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Coordinating Information and Decisions of Hierarchical Distributed Decision Units in Crises

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14. ABSTRACT *(Maximum 200 words)*:

A program of research is described. The research addressed decision making by distributed decision makers using either consensus or leader structures and confronted by both routine tasks and different kinds of information system crisis. There were three phases--a macro combining published empirical research, a simulation, and experimentation. The first phase documented that experimental research can offer very limited guidance for administrators as it only rarely investigates groups, and never organizations, in crises. The second phase exposed the challenges of combining simulations of individual (e.g., cognitive), group, organizational, environmental, and task properties as a strategy for guiding future experimental research. The third phase extended the capabilities of an organizational simulator and used it as a testbed for experiments. The simulator uses networked personal computers for all communications and records all communications and transactions between team members. Despite training in the simulator prior to experiments, participants failed to effectively exploit potential crisis response capabilities. Results suggest the importance of expanding systemic perspectives and practice with short-term redesign of available systems for people who work in distributed decision environments subject to crises. Experience with the simulator also suggested guidelines for future experiments on pseudo-organizations.

15. SUBJECT TERMS

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Introduction: Balancing Two Core Requirements

The survival of groups and organizations depends on two key processes. First, they must achieve extremely high levels of proficiency and efficiency on routine activities such as the production of products and services, maintenance of machines and software, and responding to feedback from clients or customers. This requires reliance on shared goals and beliefs, standardized patterns of behavior, convergent thinking, and intense concentration on executing plans. Second, at the same time, organizations must also provide the capability for very rapid and appropriate responses to crises and adversity (Milburn, et al., 1983a, 1983b) and adaptation. This requires early recognition of potential threats and opportunities, accurate and comprehensive understanding of new situations, divergent thinking, and (at least some) unplanned behavior. Effective organizations find ways to balance the demands for efficiencies in routine activities and readiness to notice and respond effectively to unexpected threats. Both efficiency and readiness depend upon the development of effective, high quality individual and collective decision making processes (Herek, at al., 1987).

Examination of organizational decision processes reveals that they vary widely but have several common characteristics - they tend to restrict innovation, limit the number of ideas generated and possible alternatives considered, and perpetuate doubtful practices (Nutt, 1984). Sometimes it is quite apparent that emergencies, crises, and disasters are consequences of poor decision making processes. The Cuban missile crisis (Brugioni, 1991) and Challenger (Feynman, 1992; Joyce, 1986; McConnell, 1986; Smith, 1986a, 1986b; U.S. Presidential Commission, 1986) cases are forceful reminders of this fact. Similar motivation to better understand and improve collective decision making is provided by experiences like Xerox's failure to exploit its lead in personal computers and local area networks (Smith, 1988). Perhaps too infrequently there are equally forceful reminders that inadequate decision processes not only cause, but exacerbate, existing crises, as in the Vincennes (Appendix 1) example (Burns, 1988; Moore, 1988; United States Congress House Committee on Armed Services Subcommittee on Investigations, 1993; United States Congress Senate Committee on Armed Services, 1988).

The overall objective of this project is to achieve an improved understanding of organizational decision processes designed to achieve high levels of performance in terms of both routine and crisis challenges. Better understanding requires both a systemic perspective and strong inductive methods. Thus, a combination of three methods were used in this project: macro-analysis, simulation and experimentation. Macro-analysis is designed to assess the quality and coverage of past studies in order to guide two forms of simulation research aimed at discovering better designs for organizational decision systems. One simulation form is a computer model of the key variables; the other is a simulator with distributed people performing multiple decision tasks.

Strategies for Balancing Efficiency and Readiness

Relationships, decision processes, and behaviors useful for achieving efficiency are likely to be dysfunctional for readiness. The analyses, attention to details, automation, training, communication nets and message content, and related activities which help assure efficiency can hinder responses to adversity and crises for two major reasons. First, achieving efficiency consumes resources, at least some of which could be otherwise used to achieve readiness to cope with crises. Second, because, by definition, routine activities consume most of the organizational members' time, provide most of the feedback and learning opportunities they experience, and are continuously emphasized by leaders and policies like TQM, attention is not focused on potential threats but on incremental adjustments to current routines. Similarly, achieving high levels of readiness to respond to potential threats consumes resources for activities like training and intelligence, resources which could otherwise be devoted to improving efficiency. Also, achieving readiness focuses attention more on the organization's environment than on internal processes.

One way organizations attempt to address the tension between internal (efficiency) and (largely) external (readiness) demands is specialization. To address efficiency concerns organizations rely on resources and tactics like production engineers, self-directed work teams and just-in-time inventory systems. To prepare for and cope with threat they rely on activities like strategic planning and crisis management training (of public relations and safety experts). The result is poor integration of the subsystems addressing efficiency and readiness, often followed by the organization's demise (Miller, 1990).

How can a more appropriate balance of attention and other organizational resources be achieved? Is organizational learning the answer? TQM? Trial and error? Training? For many reasons, too numerous to fully elaborate here, these and similar popular theses cannot provide clear guidance. For example, learning opportunities come form two primary sources, failure and imitation. By their nature, routine failures occur more frequently than failures due to crises. Thus, left to everyday experiences, organizational members commonly learn more about how to achieve efficiency than how to assure readiness for responding to major adversity or crises. Also, learning from crises may teach the wrong lessons. This is because members' responses to chaotic environments may themselves create "second order" chaos among members as they try to coordinate less familiar activities under severe time pressure (Ackoff, 1974). Learning is further inhibited because the increased chaos is difficult to trace back to or attribute to the well intentioned but inappropriate responses (Diehl and Sterman, 1995). Even training exercises which help members practice appropriate responses to contrived chaotic conditions are, at best, a partial remedy. Training to improve readiness for one kind of crisis (e.g., conventional war between two countries; product tampering) may interfere with improving readiness for another type of crisis (e.g., guerrilla war between a technologically advanced country and adversaries who resemble civilians; unexpected death of a key person). Further, those who design

training exercises cannot be expected to fully anticipate the intensity, novelties, or vital subtleties of future chaotic challenges (Gettys, et al., 1987).

This project emphasizes the decision process as the critical issue for achieving better balance. Whereas organizations facing the challenge of finding highly efficient routines may function best using a centralized decisions process, so too may organizations facing crises. On the other hand, in complex situations, whether routine or in crisis, a decentralized system may work best. Where the same organization or units face both the efficiency and readiness challenges they may be required to quickly shift not only their attention, but their procedures and structures. Development and maintenance of multiple decision making systems coupled with a meta-rule for selecting, and perhaps improving, the most relevant decision system, is thus a serious, even fundamental, organizational challenge.

Nature of Empirical Evidence

It would be expected that social science research can help find the appropriate balance. Unfortunately, researchers' agendas and resources produce only oblique, and perhaps misleading, implications. There are many reasons why social scientists' theories and findings have had limited relevance. First, and probably most important, their work, particularly their experimental efforts, generally fails to account for the systemic nature of organizations. Bertalanffy's (1968) general systems ideas, and Miller's (1978) comprehensive guide to the nature of groups and organizations as living systems have not been much used as guideposts by most researchers. For example Miller's emphasis on (positive as well as negative) feedback, abrupt discontinuities, adaptive capabilities, and complex interactions[1] among elements are only partially reflected in the experiments of an extremely small number of scholars (e.g., Diehl and Sterman, 1995). More typically,

> "[t]he practice of looking at isolated variables has contributed to a state of affairs where factors that make big differences in [collective] behavior are held constant because they are neither easily controlled nor manipulated in the laboratory and where potentially important intervening variables are often ignored." (Foushee, 1984)

Systemic analyses demand simultaneous consideration of numerous variables. As Ackoff (1974) noted, to examine parts of a system in the hope of understanding the whole is futile because it is the many and complex interactions among the parts which are critical, not just simple effects of one variable on another. In contrast to the large number of interacting factors with which organizational members must cope, the

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[1] Discussing the central role of interaction effects as reasons why good intentions cause crises to become more intense, Perrow (1984, p.9) noted, "...[T]he interaction of small failures led them to construct quite erroneous worlds in their minds..." [leading to actions resulting in extremely serious accidents]. (Emphasis added.)

majority of social science investigations, particularly experimental efforts, consider only the effects of one or two variables on a very limited number of dependent measures.[2]

To rely on such simple studies to obtain an accurate understanding of large systems requires valid assumptions about how to aggregate research results. It is tempting to assume simple effects combine in an additive manner. However, increasing evidence from the physical sciences (Gleik, 1987) demonstrates that small changes over some ranges of even a single variable can cause linear changes as well as sudden discontinuities and chaotic patterns in another variable. It seems unreasonable to expect the same is not true for social systems as well.

A second major factor limiting the ability of researchers to guide organizational balancing efforts is that their evidence is more uneven than their theories. The result is an asymmetry of research evidence across the individual, group, and organizational levels of systems. As will be documented by the results of this project, of these three levels of analysis, the overwhelming majority of studies, particularly experimental studies, deal with individuals.[4] However, in work and other organizational contexts, collaboration is endemic; isolated individual activities are necessary but not sufficient behaviors. It is true that some theorists (e.g., Perrow, 1984; Weick, 1989, 1990, 1993) emphasize linkages within organizational systems. To date, relatively few experimental researchers have found the resources or exhibited the patience to follow their lead.[5]

This is unfortunate. Performance on collective tasks can rarely be predicted by knowledge of the performance of individual members (Jones, 1974). In addition, failures in complex situations like flight crews face in actual (Cooper, et al., 1979) and simulator (Smith, 1979) emergencies are more likely due to defective group processes rather than insufficient (individual) expertise or technical proficiency of crew members (Foushee, 1984; Foushee and Helmreich, 1987). Yet, there were very few studies of group behavior for over 15 years beginning in about 1960 (Zander, 1979).

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[2] This is probably because psychologists have dominated most of the relevant domains. And "Psychologists ... tend to look only for solutions to problems that lend themselves to [their] methodological approaches." (Coovert, et al., 1995).

[3] There are many other variables and experiments which could be added to this argument. For example, the nature and complexity of a team member's information processing is affected by the nature of the immediate task (its size, time pressure, etc. - Payne, Bettman and Johnson, 1988), the member's integrative complexity (Streufert, et al.), the member's judgment policy (Brehmer and Brehmer, 1988), not to mention order of arrival of specific data, the member's experience or expertise, type of response required (estimate or choice), availability of decision aids, and numerous other well documented factors.

[4] This is particularly true of research on assessing and dealing with risk (Clarke and Short, 1993). Studies of intra-group communication, inter-group conflict, coalition formation, and free ridership in social contexts are obvious exceptions to the focus on individuals. However, no researchers attempt to conduct experiments at the organizational level.

[5] Concerned with numerous instances of commercial airplane crashes, two leading researchers surveyed studies of crew training and performance. They concluded, "[P]ractically all pilot ...performance research has focused on individual ... skills." (Kanki and Foushee, 1989).

Even if there were as many experiments conducted at, for example, the organizational level as there are now at the individual level, it could be dangerous to rely on findings to help organizations balance the demands of routine and readiness. The reason is that factors at the different levels of living systems (Miller, 1978) may have significant joint effects (Tomer, 1992). Because studies rarely incorporate variables from more than one level, these effects are largely unexamined.[6]

A third, related, limitation of existing research evidence is that the most systemic treatments rely on the weakest induction techniques. Anthropological and case analyses (e.g., Perrow, 1984; Rochlin, 1989; Roberts, 1990; McKinney, 1993; Eisenhardt, 1989; Miller, 1990; Feynman, 1992), and survey research do provide insights about possible causes of failures and successes in complex decision making settings. For example, Perrow (1984) used very detailed analyses of documents and interviews to document his argument that organizational members' shared experience and perspectives, while minimizing the need for communications to coordinate dispersed activities, can hinder the causal interpretation of complex events and subsequent problem solving during crises. Weick (1993) relied on existing documents to support his thesis that, in the confusion of chaotic conditions, members find it difficult to sense subtle and unforeseen causal links between changes in the states and processes of a system's element. However, the causal propositions offered by these kinds of studies need to be experimentally verified if they are to provide solid guidance for administrators (Doherty, 1993).[7]

The asymmetry in experimental research is likely to continue. Experimenters exploring the dynamics of organizational and group processes face extraordinary challenges. Each observation requires several person-hours. Experimental tasks must reflect key attributes of organizational settings. When simulators are used, as in the third phase of this project, vast amounts of data are generated, requiring substantial data reduction (for example, coding of communications) systems. Researchers' personal incentives (e.g., tenure and raises) are little concerned with rigorous experimental testing of macro propositions.

A fourth reason to rely on existing evidence very cautiously is that social scientists, particularly those who use experimentation, prefer static to dynamic contexts, especially when considering organizational level issues. For example, organizational change is typically considered in terms of evolutionary rather than radical shifts in practices and properties (Barnett, 1995). Yet for organizations, in both routine and crisis modes, change is the norm. Organizational changes are erratic, often unplanned, locally as much as systemically inspired, and sometimes dysfunctional. Even the few

[6] As an example, most researchers who consider group decision making do not incorporate either organizational contexts and variables (e.g., the nature of the organization's technology) or individuals' characteristics (e.g., mental ability) in their designs.
[7] Often this will necessitate the use of quasi-experimental studies (Campbell and Stanley, 1963).

experimenters who approach dynamics of these kinds do so with extremely oversimplified designs and challenges for their subjects.[8]

It could be argued that these objections to the utility of past research ignore experiments involving groups and teams. It is true that there has long been interest in what makes groups or teams effective. Some of the earliest research on groups focused on how different leadership arrangements affected group performance (Lewin, at al., 1939). A continuing concern has been the problem solving and decision making performance of groups (e.g., Shaw, 1932; Shaw, 1954; Steiner, 1972; Davis, 1992; Hollenbeck at al., 1995). Several group decision making studies emphasized the effects of work loads, stress, or time pressure on decision processes and/or performance (e.g., Stouffer, et al., 1949; Isenberg, 1981; Wright; 1984; Calloway, Marriott, and Esser, 1985; Stasser and Titus, 1987; Edland, 1994; Kerstholt, 1994; Urban et al., 1995; Caccaro, Gualtieri, and Minionis, 1995; Neck and Moorehead, 1995).

Despite this history of group studies, "we still know little about why some groups perform better than others (Foushee, 1984)." In addition to the factors that limit the relevance of past research to the problem of balancing efficiency and readiness, there are unique problems in group research. One is that even social psychologists very often ask individual subjects to react to "paper people" or videotaped situations rather than investigating the interactions between two or more people. In studies where participants actually interact in experimental contexts, subjects' tasks lack the complexities encountered in attempting to find an organizational balance between efficiency and readiness. Usually there is but one task to perform, only one phase of the decision process is examined, the task changes little if at all over trials, or there is no opportunity to alter the interpersonal and organizational features of the decision making system. The number of variables considered is small.[9] Because each experiment uses a somewhat different subset of variables, inconsistent results are not uncommon. Even if these problems were not present, experiments on groups may have limited relevance for achieving better balances of routine and readiness in organizations. It has been estimated that 95 percent of all studies of groups have been conducted outside "natural" settings, mostly in laboratories (Guzzo and Shea, 1990). Consequently there are numerous pertinent issues which remain to be addressed (Tuler, 1988).

The preceding arguments are well known but not taken seriously. While experimental social scientists often acknowledge in their discussions that organizations are large systems consisting of subsystems that are meshed in many ways (e.g., task coordination, information flows, interpersonal affective bonds), and while they further

[8] Researchers like Diehl and Sterman (1995) in MIT's system dynamics groups appear to have made the most progress in this respect. Even their designs involve minimal complexity compared to actual organizational settings.

[9] As argued earlier, this tends to preclude understanding of systemic effects. In this context, one researcher concerned with aircrew performance noted, "it is difficult to assimilate the sheer number of variables than can potentially affect group processes." (Foushee, 1984)

recognize that people (individually and collectively) are subsystems capable of intelligent self design, these perspectives continue to too rarely inform their empirical research. If the resources consumed by research are to be fully exploited, to speed scientific progress and increase its practical applications, more holistic projects are necessary. Fortunately, with advances in technology (e.g., computer hardware like parallel processing), software (e.g., neural networks), and statistical procedures (e.g., meta-analysis), the feasibility of more comprehensive research and assessments of bodies of research is growing. This project sought to exploit and accelerate these trends.

Systemic Research Methods

This project used three approaches in an attempt to overcome many of the problems in the literature. The first was macro-analysis. It is a new, systematic method for assessing how thoroughly all relevant aspects of complex issues have been examined by researchers. The second approach was to develop a language capable of simulating organizational decision processes, both routine and in crises. The third was to enhance and exploit an organizational simulator to conduct experiments. Each of these approaches will be explained by way of introducing each of the three major phases of this project. The importance of using these more systemic methodologies becomes more emphatic when the properties of organizational crises are taken seriously. Therefore the methodologies will be addressed following reflections on the nature of organizational crises.

Organizational Crises

Emergencies, disasters, accidents and crises are immensely important events in business (Fink, 1986; Meyers, 1986; and Miller, 1984) and military (Smith and Asker, 1993; Roberts, 1990) The flightpath ..., 1988) and other (Eisenhardt, 1993; Foushee, 1984) organizations because they can negate all the benefits of long histories of successful routine efforts.

As noted earlier, decision making in most organizations consists of relatively long periods of routine activities interrupted by infrequent crises. In contrast to routine decisions, crises typically involve surprise, extremely early deadlines, threat - the real possibility that the most important goals (including survival) will not be fully understood or satisfied, high levels of ambiguity, one or more key decision makers unavailable, (potentially) extreme individual and interpersonal stress (Herman, 1963; Herman, et al., 1974; Staw et al., 1981) and, some (e.g., Turner, 1976) would argue, very ill-structured challenges.

Crises arise from, and are accelerated by, many sources (Milburn et al., 1983a), several of which may affect an organization simultaneously. Clearly those organizations whose members lack the imagination or time to take the "impossible" seriously, or who have become complacent, or have become highly focused (e.g., on achieving extremely high efficiencies in routine operations, or on those activities which generated earlier

successes - Miller, 1990) are subject to crises. However, there should be equal concern with less emphasized sources.

Crises are often inherent in the design of complex systems which are capable of producing effects not anticipated by their designers and incompletely understood by their operators (Perrow, 1984). Crises can also arise because decision makers' reactions to events are founded on misconceptions about causes and effects. Misconceptions may be more numerous and more severe where relevant data or decision makers are "distributed" (at different locations), and/or where they lack appropriate decision aids (Sage, 1987). The very ("dominant" - Staw, et al.,1981) beliefs and behaviors learned during routine activities, as well as those acquired in attempting to cope with earlier crises, can cause or exacerbate crises. It has been observed that, "[U]nlearning may be sometimes a more difficult short-term task than learning" (Smart and Vertinsky, 1977). Insufficient variety can cause crises if appropriate responses to complex circumstances require correspondingly complex organizational capabilities which have not been developed or maintained (Ashby, 1956). Contagion may also be a factor. Messages containing even a hint of worry or stress, particularly if they are numerous and arrive at accelerating rates from many sources, may produce a vigorous sensation of panic or crisis. (Levy and Nail, 1993; Hatfield, et al., 1994)

Examples of all these sources of crises can be found in human creations like technology (e.g., Boeing's "fly by wire" technology in the 777), economic activity (e.g., unauthorized trades in futures markets), and geopolitical events (e.g., the Suez crisis of 1962). In addition, it is important to recognize a fourth human source of crises. Their number, frequency and intensity depends on the quality of both routine and crisis decision making activities. Poor routine decisions foster crises. Poor decision making during crises exacerbate rather than resolve crises.

Both routine and crisis decisions are handicapped by lack of imagination[10] and misunderstanding. In his analyses of "normal accidents" Perrow (1984) offered Three Mile Island's nuclear power plant as an example. Those who designed and constructed the plant were not the same people who operated and controlled it. Despite extensive training and rehearsals in simulated emergencies, operators' grasp of what could happen in many contingencies was limited or non-existent. Perrow's minute by minute documentation of reactions to the leak at Three Mile Island revealed that engineers' beliefs about what was happening in the system were sometimes the opposite of actual events. Hence, at times, their discussions and decisions not only failed to help control the plant, but increased its instability.

Even where technologies are better understood, crises may arise from the cumulative effects of small, virtually undetectable, events (Gersick and Hackman, 1990; Weick, 1990). For example, Weick (1990) argues that, among other apparently minor factors,

[10] A spokesperson for Japan's Mihamam nuclear plant said, "We never thought that the radiation could increase so quickly because such a thing hadn't happened before."

small changes in plans or routines coupled with regression to first (and best) learned behaviors under stressful conditions, "hearing" what one is anticipating will be said (rather than seeking clarification of confusing messages), and reluctance of inexperienced participants to question superiors were keys to the crash (on the ground!) of two 747's and the loss of nearly 600 lives.

Perrow and Weick agree that serious crises are most likely in "tightly coupled" systems. Tightly coupled systems have very many elements,[11] few if any redundancies, and complex but strong cause-effects linkages. "Coupled" is misleading because it seriously understates amplification. As Weick emphasizes, where success requires the small events to occur in proper sequence, failure of one event to take place at the right time and as planned greatly multiplies the risks of severe failure of the larger system. Weick also notes that loosely coupled systems may very suddenly become extremely tightly coupled when many "small" events have unrecognized but amplified consequences.

Well intentioned decisions and actions, particularly when taken in the context of incompletely understood systems, may cause new crises or increase the severity of existing crises. For example, when the Chernobyl nuclear plant was being operated at reduced power during a routine maintenance operation, experiments were undertaken. Although it remains unclear exactly what the purpose of the experiments was, they involved investigation of the effects of changes in control rod positions on the safety system's performance. A United Press (1986) report noted:

> "The investigators think the operator pulled out some control rods and upset (the) delicate balance.... 'Alarmed, he moved some more rods to try to get the situation back under control - and this caused part of the reactor to 'go critical.'""

Even when people are well intentioned, when they seek to avoid crises and minimize their adverse effects, they create organizational and institutional arrangements which initiate or expand crises (Clarke and Short, 1993). A vivid example was the Chicago flood of 1992 which resulted in more than $1 billion in damages and lost income (Bailey and Burton, 1992; Freak flood ..., 1992). Early in the century, tunnels beneath the city's center were dug in order to provide deliveries of goods and removal of waste without adding to the congestion of surface transportation systems. In 1991, when a "rational" activity, the replacement of decayed wooden bumper posts which protected bridges over the Chicago River from being struck by ships and barges, was not carefully planned and monitored, the replacement piles were driven through the bed of the Chicago River and top of one of the delivery tunnels. It should be noted that complacency, arrogance or incompetence also helped cause this crisis; authorities had been warned (with photos and video tape) about leakage from the river into the tunnels. Remedial action had been delayed because the city sought additional bids which were

[11] Perrow (1984) emphasizes six sources of failure in tightly coupled systems with the acronym DEPOSE, Design, Environment, Procedures, Operators, Sources/materials, and Equipment. Of these, at least 60 percent of most crises or accidents in complex or advanced technology systems are attributed to human components, the operators.

lower than those originally submitted. "It's a lot of little actions that led up to a disaster," said John Laplante (the later fired) Director of Transportation. "A lot of what happened are honest and competent employees making errors of judgment."

Crises often are the result of cumulative ineffectiveness which is difficult to detect. There may be no single or "large" weakness in the decision system. Those "small" weaknesses[12] which are present are not fatal in isolation, and they are often manageable. Many decision system features are double edged but viewed solely as assets. For example, the development of shared mental models, while reducing communications needs, also reduce hypothesis generation capability, reducing creativity and innovation. Similarly, interaction (Stasser, et al., 1989; Heath and Gonzalez, 1995), or shared or redundant (Slovic, 1982) data can help cut costs and time for search but tend to unconsciously inflate confidence. In short, despite the presence of positive attributes in organizational systems, there is a real, perhaps large, possibility that "small" weaknesses aggregate in complex (e.g., multiplicative) ways, cumulating in a crisis.

An example of the multiplicative impact of small events in tightly coupled human and technological systems, and of good intentions gone awry, involved the electrical power, telephone, and airline industries. Late in the afternoon of September 17, 1991, AT&T suffered a loss of power[13] which forced the air traffic controllers in the New York city area to shut down most of their operations.[14] Controllers in New York lost 90 percent of their communications capability with adjacent on Long Island. Thus, New York controllers could not "hand off" flights that were leaving the 200 mile radius for which they were immediately responsible. They also lost 50 air to ground frequencies used to communicate directly with pilots. As a direct result 1,174 flights carrying 85,000 passengers were canceled or delayed; 100 planes sat idle on runways for four hours.[15] Later the FAA claimed there was no safety threat to passengers and crews.

How did this crisis arise? Explanations focused on four causes.

1) An earlier FAA request to the General Service Administration (GSA) for parallel, redundant systems using AT&T and (e.g., MCI) had been denied by GSA on the basis of cost.
2) To try to save money, AT&T had an "interruptable power" contract with Con Ed.
3) The afternoon of September 17th was unexpectedly, unseasonably hot causing huge air conditioning loads on Con Ed's generating and distribution systems. Con Ed decided to interrupt power for firms with contracts like AT&T's.
4) AT&T responded to Con Ed's notice that power would be cut by switching to its own generators.

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[12] "[G]reat events have small beginnings." (Perrow, page 9.)

[13] This failure was despite several billion dollars spent by AT&T to assure a "self-healing" system.

[14] This was the third time since January 1990 in which a major failure in the AT&T system was experienced (at least one of the earlier ones was due to the use of new software which contained a bug).

[15] Airport and airline operations were only part of the story. 470,000 international, and 4.5 million domestic, calls didn't get through. Some of them certainly were emergency calls.

The generators were not on the same floor as the one occupied by those monitoring the system. So when rectifiers (which change AC to CD current) blew, switching AT&T's system to battery operation, monitors were relying on a warning system. At the time, that warning system was:

a) Not operating properly (some audio warnings were muffled, some lights were not functioning or had been disabled), and
b) Ignored by AT&T's operating personnel and their supervisor because they were at a training session learning about a new warning system, and
c) Ignored by managers who, substituting for the trainees, failed to assure that previously specified procedures were followed..

After six hours of use AT&T's emergency batteries had not been replenished, power fell, and telephone switching equipment failed.

Fortunately, the concatenation of a) "good" decisions (to economize - AT&T and the GSA, and to provide technical training - AT&T) with b) extreme conditions, and c) tight couplings among the three industries did not cause a major airline disaster.

Decisions made during crises may also intensify the crises due to reliance on mindless use of information (Langer, 1992), an inability to shift from automatic to conscious cognitive activities (Louis and Sutton, 1991), habitual thinking and processes (Gersick and Hackman, 1990), and inflexibility or organizational routines (Weiss and Ilgen, 1985). Even substantial departures from normal conditions may not be sufficient to alter rigid patterns of thinking and interaction. It has been argued that the crash of Florida International's flight 90 into the 14th Street Bridge in Washington, DC (National Transportation Safety Board, 1982) was such a case. Of course, crises typically increase time pressures on decision makers, and would be expected to cause a shift to less rigid, more mindful (Langer, 1989) processes. However, in at least one study in a dynamic environment, decision makers relied on the same decision making strategy no matter how much time pressure they experienced (Kerstholt, 1994).

Social and economic systems contain not only complex technologies, but webs of causes and effects which are often less salient than technological linkages. Thus, in the realm of economic and business decisions it is reasonable to expect that the combination of complex systems and inappropriate understanding of those systems will frequently exacerbate crises. It has long been documented that instability in complex situations is caused by decisions founded on misinterpretations of feedback data. For example, in the classic beer game experiments, participants' attribute cyclical demand to fluctuations in consumers' decisions, whereas demand changes only once (Sterman, 1989). Even though participants are very intelligent, are subject to market discipline, and have strong performance incentives, and even though the system they are asked to manage is quite simple, their choices, not the single exogenous shock the system receives early in the experiment, create and sustain instability.

In the areas of diplomacy and international conflict it is, unfortunately, common to find instances where crises originated or were escalated by decision makers who were well intentioned but unable to adequately grasp the social and geopolitical elements of the

situation. McNamara's observations about the decisions made in the Kennedy and Johnson administrations reveal that the sacrifices made during the Vietnam war were magnified by top decision makers' ignorance, misconceptions, and misinterpretations (McNamara, 1995). Social reinforcements for these cognitive problems were provided by syncopates and peers, compounding the problems and crises.

Experienced decision makers know that crises arise from subtle combinations of nonsalient and unanticipated causes, and that effective responses depend on early recognition, and appropriate responses. They know teams and organizations can fall in to "self-fueling spirals" (Hackman, 1990). Their performance tends to decline (improve) if they somehow begin on a good poor (good) track. For example, in fighting forest fires early detection coupled with very quick and very well learned, appropriate responses are the keys to controlling damage and minimizing the resources used to control the crisis (Klein, 1976; Klein, and Calderwood, 1991; Mclean, 1992;). Appropriate responses demand expert knowledge about how different combinations of fuels, terrain, temperature, humidity, and other "technological" considerations affect the crisis. Moreover, "social" knowledge is critical. Among other things, appropriate decisions by a commander require assessments of human endurance; the current locations and capabilities of team members; their knowledge of local terrain; and how effectively "headquarters" will be able to marshal additional supporting resources (such as weather forecasts for the immediate area, relief personnel, air tankers, and satellite photos).

Correct interpretations of events and of the utility of decision alternatives is likely to be hindered when superiors fail to seek and use their subordinates' ideas and information. Among the more subtle factors that may influence the willingness to use subordinates' inputs, particularly those which disagree, is the superior's assessment of the situation (Weick, 1993). One study found that when the situation was viewed by a superior as either a crisis or as a minor issue, subordinates' contradictory inputs were unlikely to be used to make constructive use of their suggestions (Tjosvold, 1984). However, when superiors regarded the situation as a challenge, subordinates' information and dissenting opinions tended to improve the superior's decisions.

Crises may also be caused or escalate because decision makers do not initially analyze matters using complex integrations of perspectives, or because their integrative complexity declines as perceived threat increases, or because they feel little or declining accountability to others (Levi and Tetlock, 1980; Mandel, et al., 1993; Walker and Watson, 1994).

Contrast this abbreviated litany of the nature and sources of crises (or review Appendix 1) with the earlier characterization of research. It is hoped that the comparison has motivated two things: 1) the reader's interest in research methods which provide better integration of the many relevant variables, and more rigorous inductive treatment of complex systems.

Macro Analysis of Relevant Research - Phase 1

Macro- and Meta-Analysis

The first phase of the project was labeled a "macro-analysis" to distinguish its objectives from those of meta-analyses. The concern is epistemological. Macro-analysis procedures were developed as a complement to meta-analysis and to encourage more symmetry and thoroughness in research on systems like distributed decision making systems. The purpose of meta-analysis is to estimate the true size of effects on a dependent variable (e.g., judgmental accuracy) caused by variations in one or more independent variables (Hunter, and Schmidt, 1990, 1991, 1994). Effect sizes are adjusted for factors in the relevant set of studies which can bias or affect the magnitude of effects in any one study (e.g., restriction of range and sample size). In essence, each study is one observation in the meta-study of all the studies which investigate the same hypothesis. Meta-analyses have proved valuable in resolving apparent conflicts in studies' findings, achieving not only more accurate estimates of effect sizes, but also identifying situations in which moderator variables may be affecting effect sizes.

Meta-analyses cannot be conducted on any issue where there are only a few studies of the issue. Thus, the set of meta-analyses found in a literature is an implicit indicator of the research focus of social scientists. However, meta-analysis does not systematically identify research issues which could or should be subjected to strong inductive treatment. To systematically identify important unresearched issues it is necessary to conduct "macro-analyses" of past research.[16] Macro-analyses are particularly important where scientists are attempting to understand complex systems which require analysis by multidisciplinary teams.

Macro Analysis Procedures

In many important ways the steps of macro-analysis are quite different from those in meta-analyses. Meta-analysis has a reductionist quality in that it usually examines pairs of variables.[17] In contrast, macro-analysis emphasizes systems of relationships among pairs of variables as well as interactions between two or more variables. Whereas both kinds of analysis require discovery of relevant research, relevance is defined very differently. Macro-analysts must determine which variables are to be included. In contrast, in the most basic meta-analysis the two variables in a proposition or hypothesis of interest, as well as their synonyms, are used as key words when searching the titles, abstracts, keyword lists, and texts of research reports. As will be seen, many more variables are involved in macro-analyses. Normally meta-analyses scan not only studies in peer reviewed journals, but technical reports as well. Macro-analyses must focus on research published in peer reviewed journals to remain feasible. Once a body of relevant studies is identified, meta-analysis codes each study's characteristics (e.g., sample size) and transforms data where appropriate (e.g,

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[16] There are other advantages of macro-analysis as well. It can document the extent to which specific methodological treatments and paradigms extend across disciplines and time.

[17] This oversimplifies somewhat. Meta-analyses concerned with moderator variables or interaction effects involve more than two variables.

from correlation coefficient to difference score), before conducting more statistical analyses to adjust raw effect sizes into estimates of actual effect sizes.

Macro-analysis parallels early steps in meta-analysis but stops before relevant studies are coded. Macro-analysis begins by identifying a system, parts of which have been the subject of (experimental) research but which is still imperfectly understood. The next step involves developing a list of variables which reasonable people believe are pertinent to the set of issues or system of interest. The list of variables should be as exhaustive as possible. To encourage the development of a comprehensive list, macro-analysis must review more than experimental or other research. It is important to read cases, journalistic and technical reports, historical narratives, and documents in files. It is also important to question participants who have been involved in relevant experience.[18] As the list of variables develops care must be taken to identify synonyms and antonyms to avoid redundancy. In many systems involving human actors two or more variables interact to affect a dependent variable. In such cases the interacting variables may be treated as a single (joint) variable in the key list.

The next step in macro-analysis is to construct a square matrix using the list of key variables twice, once for the rows and again for the columns. Each row will contain all references to studies in which a variable has been treated as an independent variable in a study. Each column will contain all references to studies in which a variable has been a dependent variable. Thus each cell represents a simple research proposition involving a pair of key variables. When an experiment containing at least one pair of independent-dependent variables in the list of key variables has been identified, the experiment's index number is entered in the appropriate cell(s) of the matrix. Thus, an experiment's index number would be entered in two cells if that study examined the effects of status incongruency on satisfaction with a team's decision process and also examined the effects of satisfaction with decision process on status congruency. Ultimately each cell of the matrix will contain an unique number for each study which examines the cell's hypothesis.

After the numerous variables related to the focal system have been identified, it is necessary to identify relevant studies. Prior to the introduction of computerized data bases this was not feasible for issues involving large systems or many variables. However, with the development of computerized abstracts in PsycLIT[19] it is possible to conduct reasonably efficient searchers using Boolean logical operations.

Once all studies are indexed and their index numbers have been entered in appropriate cells, several insights can be obtained simply by visual inspection. One is the density of researchers' attention to variables and hypotheses. It is immediately apparent that where there is a high density cell, that is, where there are numerous studies of an

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[18] Many good examples of this kind of canvassing of participants can be found in Mowen, 1993.
[19] This data base now contains abstracts for journal articles from 1967 to the present. It also references book chapters from 1967 to 1987 and abstracts book chapters published since 1987.

hypothesis, a meta-analysis is likely to be fruitful.[20] A row with few index numbers entered in any of the cells may indicate an independent variable that either needs more study, is implicitly judged to be of limited relevance by researchers, or is simply very difficult to examine.

Overlays of multiple matrices can be particularly useful.[21] Suppose that one wished to address the idea that research in laboratories with ad-hoc student groups provided different conclusions than research relying on "real" people in on-going teams in field settings. If an overlay of the two matrices, one for each type of study, revealed different patterns of density for one type than for the other, it would indicate that conclusions from one setting cannot be generalized to the other. Another useful overlay is to have three matrices, one for studies finding no effects, another reporting positive effects, and a third reporting negative effects regarding a specific cell's research question.

Overlaid matrices can examine method variance effects by comparing the loci of studies in one matrix summarizing experiments with another summarizing survey research. Or a researcher concerned with differences between the effects of noise in communications on small group and organizational judgmental accuracies might use one matrix for small group studies and a second matrix for organizational studies. Multiple matrices can also be useful when paths of effects among dependent variables are considered.

Transformations of the original matrix may also prove useful. Where definitions, theories, or clear empirical patterns can justify doing so, certain variables can be aggregated to provide better insights about what can be concluded from a literature. An example of this approach was used in this project and will be discussed shortly.

Macro-Analysis of Phase 1

The macro-analysis in the first phase of this project had two main objectives. The first was to prioritize future research by identifying gaps, redundancies and conflicts in previous studies. The second was to discover standards, variables, and relationships to be used in construction of simulations in the second phase of the project.

More than 80 key words or phrases[22] (in Appendix 3) related to distributed decision making in routine and crisis settings were identified. This was accomplished by reading a wide variety of sources in addition to the experimental literature on decision making.[23]

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[20] Even where there has been a meta-analysis of a cell's hypothesis, the density may suggest a newer one could be conducted to incorporate studies not included in the most recent meta-analysis.

[21] With overlaid matrices it may prove useful to develop mathematical comparisons, such as similarity measures. This project did not require such sophisticated capabilities.

[22] There were originally 69 key words or phrases. New ones were added as the literature search progressed to assure a complete canvass of the literature.

[23] Unfortunately, as is obvious, not all these sources were available at the time the list of key variables and phrases was being developed. This section includes only examples of the many sources used during the project. For a complete listing consult the references section of this report.

Among the major sources were detailed accounts of events like Wal-Mart's growth (Trimble, 1990; Vance and Scott, 1994), the Cuban missile crisis (Janis, 1972, 1982, and 1989; Janis and Mann, 1977; Anderson, 1983; Brugioni, 1991; Sylvan and Thorson, 1992; Guttieri et al., 1995), NASA's decision to launch Challenger (Covault, 1986; Joyce, 1986; Smith 1986a & 1986b; US Presidential Commission, 1986; McConnell, 1987; Browning, 1988; Kolcum, 1988; Feynman, 1992); Xerox's decision not to market it's "office of the future" (Smith, 1988), the Chicago flood (Freak flooding..., 1992; Bailey and Burton, 1992), forest fires (Mclean, 1992; Weick, 1993; Sahagun, 1994), the Navy's shooting down of a civilian airliner (Burns, 1988; Moore, 1988; The flightpath to disaster, 1988; US Congress Senate Committee..., 1988, and House Committee..., 1993; Rogers, 1992), Chernobyl (Cohen, 1987; Brandsjo, 1988; Martinez-Val, 1990), Three Mile Island (Perrow, 1984) and other high technology emergencies (Tuler, 1988), aircrews in crises (National Transportation Safety Board, 1982; Foushee, 1984; Helmreich et al., 1985; Foushee and Helmreich, 1987; Lanir, 1989; Ginnett, 1990, 1993; Weick, 1990; Deitz and Thoms, 1991; Helmreich and Foushee, 1993; McKinney, 1993; Lavin, 1994), infrastructure failures (e.g., Lavitt, 1991; McKenna, 1991), and operation of high reliability systems (Cooper et al., 1979; Rochlin, 1989; Weick, 1989; Roberts, 1990; Clarke and Short, 1993; Eisenhardt, 1993; Weick and Roberts, 1993). Ethnographic and case studies (e.g., Nutt, 1984; Mulder at al., 1986; Hickson, 1987; Kuklan, 1988; Prechel, 1994) were examined. In addition, literature reviews and meta-analyses (e.g., Maass and Clark, 1984; Brehmer and Brehmer, 1988; Levy and Nail, 1993; Lopes, 1994; Mullen et al., 1994; Salas et al., 1995; Guzzo and Dickson, 1996), simulation articles (e.g., Carley, 1986; Brannick, et al., 1993; Coovert, 1995), editorial opinions, theories and models (e.g., Hertzler, 1940; Mackenzie, 1976; Billings et al., 1980; Heiner, 1988; Kaplan, 1983; Miao, 1991; O'Hare, 1992; Klein, 1993; Lewis and Sycara, 1993; Proulx, 1993; Barnett, 1995), and essays (e.g., Churchman, 1971; Milburn, 1977; Smart and Vertinsky, 1977; Staw et al., 1981; Milburn et al., 1983; Miller, 1984; Fischhoff, 1985; Langer, 1989, 1992; Eisenberg, 1990; Gersick and Hackman, 1990; Beach and Lipshitz, 1993; Larson, 1993; Thietart and Forgues, 1995) have been unsystematically monitored since 1988.

In a series of Boolean searches of all studies from 1983[24] to 1991 in PsycLIT,[25] 60,888 unique,[26] potentially significant, studies were identified and downloaded. Each abstract was then screened to determine whether or not the study should be retained for further

[24] When this project began Psychological Abstracts did not include abstracts for studies prior to 1983. The macro-analysis was supplemented by on-line searches of PsycLIT as pre-1983 and post-1991 abstracts were added to the PsycLIT data base. The additional studies from those periods did not change the results of the original macro-analysis.

[25] Many other sources were consulted, but they proved less complete or redundant with PsycLIT. Among those sources were the following on-line data banks: ABI/INFORM (management and administration), ERIC (education, measurement, personnel training), NTIS (social sciences), SOCIAL SCIRESEARCH (social- behavioral sciences), and SSIE (social and engineering sciences).

[26] No single search could cope with the entire set of key words. The searches excluded all studies not involving adults. Over 250 searches were ultimately conducted to assure a thorough examination of all relevant research. Duplication was eliminated using specially written computer programs. Other custom programs were used to streamline abstracts for faster and more accurate reviews.

analysis. Twenty one[27] criteria (Appendix 4) were used to delete irrelevant studies. A sample of abstracts was evaluated by at least two trained coders and audited by the author to assure consistent treatment. Custom programs were used to remove redundant or irrelevant studies whenever possible. These activities resulted in 1,523 studies to be reviewed.[28] Simultaneously articles in many scientific journals (Appendix 5) were studied. Those articles deemed to be relevant were compared to the articles identified by the PsycLIT search process to assure the search was thorough. No oversights were discovered.

The number of studies, on average, in each cell of the first macro-analysis matrix constructed in Phase 1 was fewer than 0.5, suggesting that most issues relevant to distributed decision systems functioning in crises contexts had received minimal attention. However, none of the logical or theoretical relationships between the 80 variables in the matrix had yet been used to sharpen the focus. Two consolidations were performed. First studies based on synonyms were placed in the same category. Second, the variables were divided in to two sets, those emphasizing aspects of the decision process, and those that focused on the constraints and context within which the process takes place, or on the consequences of the processes. (These two sets are listed in Appendix 6.) A second matrix was constructed using the first set as columns and the second as rows.

While working with the second matrix it became obvious it would not be possible to develop a meaningful propositional inventory for two reasons. The first was that the modal cell in the first matrix was empty. That is, there had been no study of most possible pairwise relationships among key variables. Where there was more than one study, there were very few and their results were usually inconsistent. These limitations will be evident in other sections of this report. For example in the discussion of stress, a series of propositions is provided. Readers will note that most of those propositions are founded on a single study and that coverage of issues is very uneven.

The second reason a meaningful inventory was not possible is that abstracts in PsycLIT contained too little information to index most studies. Thus, to complete a propositional inventory would have required each member of the research team to read and code more than 500 studies in addition to their other project activities. In an attempt to achieve as much closure as possible a third matrix was developed. It consolidated the 52 rows of the second matrix in to eight categories (which are defined at the bottom of Appendix 6). The following table indicates the number of studies which could be clearly coded in to one of the cells of the third matrix.[29]

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[27] Two were added to the original 19. Studies must have been experimental and published in peer reviewed journals.
[28] In the following discussion additional studies are included due to searches that became possible in later years of the project.
[29] Note that, unlike the first macro-analysis matrix which addressed a single proposition in each cell, a cell in this table may contain studies of many different hypotheses. Thus, even those cells with several studies usually do not imply the possibility of a useful meta-analysis.

Table 1
Categorization of Relevant Studies

	Accuracy	Risk	Environ-ment	Mental Model	Crisis	Outcomes	Collective	**TOTALS**
Assessment	21	11	5	10	7	3	44	**101**
Choice	84	161	56	86	32	100	261	**780**
Communicate	19	8	7	11	16	0	74	**135**
Estimation	16	42	1	8	8	15	32	**122**
Forecast / Prediction	29	18	2	30	12	3	58	**152**
Judgment	39	133	0	10	5	1	43	**231**
Knowledge / Information	35	21	5	17	13	4	58	**153**
Search	7	8	0	6	1	5	10	**37**
Memory / Learning	8	8	6	10	8	10	32	**82**
TOTALS:	**258**	**410**	**82**	**188**	**102**	**141**	**612**	**1793**

As these data suggest, the macro-analyses revealed that experimental foundations for recommendations to improve organizational decision making are seriously limited. There are extraordinary asymmetries. Inspection of the margins in Table 1 immediately reveals that studies of decision making in crisis contexts are unusual, constituting fewer than six percent of all studies on aspects of decision making. Another striking observation is that only about one third involved dyads, groups, teams or some other form of collective activity; studies of individual cognitive behavior received disproportionate effort. An equally disturbing limitation is the fact that, even though an essential step in effective team decision making in crises is accurate definition of the situation, fewer than two percent of the experiments addressed one or more elements (e.g., search, creativity, attention, coordination) of the definition process.

The asymmetries are even more striking when the data in Table 1 are considered in more detail. The cell representing studies of intra-team or intra-organizational communications in crises contains fewer than one percent of all the studies. The same is true for the cell pertinent to search in crisis conditions. In contrast, 20 percent of all the studies have examined facets of judgment, estimation, choice and forecasting in risky situations.

Some other asymmetric results of the macro-analysis are not apparent in Table1. Studies with provocative findings (e.g., the interest team members show in others' ideas is greatest in moderately challenging settings and is lower in crises)[30] are almost never

[30] Similar patterns were found for expression of disagreement with positions opposed to one's own position. These kinds of findings may imply that team members in crises can quickly find an inappropriate, but apparently consensual, definition of their situation. This was apparently the case of the technicians at Japan's Mihamam nuclear plant February 9th and 10th, 1991. According to the

replicated. The modal experiment involved fewer than three independent variables, each having just two conditions. Single level designs dominated even though individual characteristics (such as amount of stress), team characteristics (such as cohesiveness), organizational characteristics (such as allocation of decentralized task responsibilities) and environmental features (e.g., amount of threat) are likely to interactively affect decisions processes in crises, there were virtually no experiments using one or more independent variables from each of these three levels. Typically, subjects in experiments were not required to face the consequences of their own previous judgments/decisions in subsequent decision processes as is normal in "real world situations. Most subjects were inexperienced high school or college students.

These characterizations of relevant studies appeared to be too extreme. Therefore, to assure that the conclusions from the macro-analysis were not overstated or misstated, a series of additional searches of the PsycLIT abstracts was conducted. A brief description of one of the additional searches will demonstrate the procedure and the nature of the findings. It supposes a researcher is concerned with how any set of decision makers, whether or not they are distributed, copes with the onset of a crisis. Key activities at that point include sensing the situation accurately, creating potentially useful action plans, and collaborating effectively.

The following lexicographic Boolean search was used to identify studies relevant to these concerns. The first two steps assure that only studies of collective (e.g., dyadic or larger groups' or teams', and organizational) behaviors in the face of severe time pressure, threat, or crisis were considered. The third step assured that, of the studies selected in the first two steps, only studies concerned with attention, creativity, and collaboration issues were be selected.[31]

Step 1: Select any study involving at least one of the following key words or phrases.

Stress, Anxiety, Tension, Threat, Crisis, (work) Load, Time Pressure
(This step produced 183 potentially useful studies.)

Step 2: From the studies identified in Step 1 select any study involving at least one of the following key words or phrases.[32]

Team, Group, Distributed, Organization, Integrati*
(This step eliminated all but 78 of the 183 studies identified in step 1.)

Step 3: Of the studies remaining after Step 2, select any study involving at least one of the following key words or phrases.

Set 1: Search, Attention, Scan, Definition, Formulat*, Problem Space
Set 2: Creativity, Innovation, Hypothesis Generation, Invention
Set 3: Coordinat*, Communicat*

Associate Press, they interpreted a warning signal as a defective signal rather than an indication of the (actual) radioactive leak.

[31] In fact, the "OR" logical operator was applied to all the keywords or phrases within a given step or set. The "AND" operator was then used to condense the three sets into the final set of potentially relevant studies.

[32] A key word containing * is used to identify all studies with the same stem. For example, Integrati* will identify all studies with integration, integrating, ...

Set 4: Cognitive Complexity, Cognitive Style, Cognitive Map, Mental Model, Policy, Script, Schema, Image Theory, Experience, Expertise

The third step eliminated all but 41 of the 78 studies which remained after the second step.

Reading the 41 studies revealed that fewer than half, 19, were actually pertinent to some aspect of the early phases of collective coping with crises.[33] The 19 studies reported 12 dependent variables[34] that were significantly affected by one or more independent variables. Most hypotheses were addressed by only one study. For example, of the 19 pertinent studies, only one compared experienced with ad-hoc groups (Kanki and Foushee, 1989). Whether in routine or crisis situations, flight crews that had flown together had more task oriented communications, more frequently sought to validate understanding of messages, and exhibited more participation by subordinate officers when working in a flight simulator than newly formed crews.

Attempts at replication were the exception in the 19 studies. Of the 12 dependent variables, only two were examined in more than one study. In both cases there were only two experiments. In one case the first study's results failed to be replicated by the second. Hansford and Diehl (1988) found no effect of sex on idea generation whereas (Mabry, 1985) found males made more suggestions in structured tasks whereas females made more in unstructured tasks. In the second case, two studies by the same researcher were concerned with overall group performance in rule induction tasks, but examined somewhat different sets of independent variables (Laughlin, 1988; Laughlin and McGlynn 1986). In both experiments exchanges of evidence fostered performance more than exchanges of hypotheses. This replication of findings was a notable exception to the general patterns found in the macro-analyses.

Similar stepwise Boolean searches of abstracts were conducted for additional topics (e.g., studies of which factors affect groups', teams' or organizations' effectiveness when making routine decisions). In every case the number of pertinent studies which were located were very few. In most cases each study had an unique combination of variables. Where two or more (a very rare event) studies considered the same hypothesis, different results were usually obtained.

Due to these, and other less serious, limitations, Foushee's (1984) lament about our ignorance of group behavior remains accurate. It applies even more to organizational decision making in crises. Consequently the second phase of the project, development of ICARUS, rested on the research team's judgments. This was particularly true when considering how teams or organizations sense when there is a crisis, what the nature of the crisis is, and what responses might be appropriate.

[33] A Boolean search for studies which focus on how collective choices are made in crises resulted in 34 studies, only 5 of which were pertinent. Similar severe "shrinkage" was experienced in all searches of this kind.

[34] The 12 dependent variables were: idea generation, overall communication, task-related discussion, validation of information, non-task discussion, interest in opposing arguments, disagreement with opposition positions, decision effectiveness, decision speed, group performance, and individual power.

Simulating Decision Making Systems

In its second and third phases this research program used two simulation approaches to balance the competing demands for systemic, yet causal empirical analyses, logistical challenges, data capturing and reduction, and realism.[35] One approach, which was used in the third phase and will be described later, hereafter referred to as a simulator (or ALCO), was in the tradition of experiential games and war games. Much like a flight simulator, it permits researchers to observe the decision making processes and outcomes of participants who play specific roles in an organizational context. The second simulation approach was to construct a simulation language, ICARUS, to create computer models of organizational decision making systems.

ICARUS sought to incorporate variables and relationships whose critical nature have been documented by prior empirical studies or rigorous analyses. There were two ultimate goals. One was to conduct "thought experiments" (Davis and Kerr, 1986) to determine under what conditions different simulation's results paralleled previously documented behavior. The second was to guide the design of experiments on the organizational simulator (ALCO) which followed in the last phase of the project.

Simulation techniques are widely used to better understand how to manage crises associated with complex technologies like the space shuttle and nuclear power plants (e.g., Kolcum, 1988; Martinson and Hobbins, 1991). However, most previous research efforts of this kind, (e.g., Carley and Prietula, 1994) have not explicitly relied on empirical (experimental or survey) research. Nor have they been validated with subsequent empirical investigations.

The advantages (and limitations - see Burton and Obel, 1984) of computer simulations for studying the behavior and design of organizations have long been recognized (Cyert and March, 1963; Abelson, 1968; Oron et al., 1984; Cohen and Cyert, 1965). The most important advantage is integration. The number of variables and relationships incorporated in a simulation can more closely approximate those found in complex systems like organizational decision making systems. Unfortunately, existing simulations have made relatively small advances in this sense. For example, simulations of individual decision making processes do not yet include other relevant individual factors like emotion (Carley and Prietula, 1994). Nor do models of individual cognitive processes like SOAR (Newell, et al., 1989) contain organizational variables or relationships. Likewise, there is no notion of individual cognitive activity in the organizationally oriented Garbage Can simulation (Masuch and LaPotin, 1989).

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[35] Analytic models (e.g., Boettcher and Tenney, 1986) can add human information processing characteristics to normative (in their study, team theoretic) models to produce provocative hypotheses about how to structure distributed decision making processes. However, computational constraints require analytic models to exclude all but a very small number of variables and relationships which are present in actual situations. Thus, simulations may be the only way to encompass the complexity of real crisis management systems with many team members at critical nodes in the network.

Simulations like Stasser's (1988) DISCUSS model of intra-group information flows do not incorporate inter-group (intra-team) information flows, team structure, or any other "macro" variables. Carley's ELM emphasizes organizational features (distribution of relevant information and alternative structures) but intentionally minimizes attention to individual behavior. Even simulation research which explicitly addresses individual and organizational factors exhibits minimal integration (Carley and Prietula, 1994). A truly comprehensive simulation which encompasses the many variables, relationships and levels of analysis inherent in decentralized decision making teams is likely to therefore provide surprises when used as an experimental vehicle (Stasser, 1988).

A second advantage of comprehensive simulations is that their construction reveals how vague and incomplete existing theories really are. These revelations, like the surprises, stimulate new insights and more thorough consideration of the foundations upon which empirical studies are constructed and evaluated. When gaps in theories or empirical understanding are identified, construction of simulations require explicit assumptions which may be used as hypothesis in experimental work. Strategic choices among alternative research designs and methods are therefore better informed.

A third reason to use simulation is that it can better capture the critical dynamics of reality than other research methods. Unlike most empirical research, a good simulation should be capable of suggesting the consequences of cybernetic, non-linear, discontinuous, and chaotic relationships among variables and processes which are central to organizational decision making activities from search through choice. Research failing to explicitly deal with these intra- and extra-organizational dynamics seems likely to be irrelevant at best, if not actually dysfunctional, to better understanding of how real decision systems work and how they can be improved.

A fourth major advantage of the comprehensive simulation is that, once constructed, it can be used for a very wide variety of inexpensive and quick thought experiments to assess propositions and complex models obtained from researchers, on-line decision makers, and those who carefully observe decision making processes. No other method permits experimental treatment of such complex, dynamic issues as inexpensively or quickly.

There are several major disadvantages of simulation as empirical research vehicles. By far the most important is the magnitude of the task. In this project characteristics of individual and collective behavior must be carefully specified and linked. And those elements must be linked to equally carefully defined environmental and task characteristics. Examination of existing simulations[36] reveals that they are limited to

[36] Simulations range from those stressing individual information processing, judgment and decision behaviors (Hastie, 1988; Payne, et al., 1988), through various forms of collective behaviors (Huesman and Levinger; Hastie and Pennington, 1989; Markovsky, 1987; Stasser, 1988, Hollenbeck, et al., 1995), to organizational (Cohen, 1982; Cohen, March and Olsen, 1972; Marsuch and LaPotin, 1989) decision making systems. The project most like this project appears to be ACTS, (Carley and Prieula, 1994). They are usually founded on, and replicate, behaviors

about six key parameters; too few to capture the complexity of most important organizational decisions, particularly those made during crises. Despite such challenges, in view of the advantages of simulation, there is almost no alternative to a project like ICARUS for researchers who take the systemic nature of organizational decision making seriously when constructing and testing theories which could inform practice.

Phase 2 - ICARUS

A goal in both simulation phases of this project was to avoid the necessity for "starting over" each time a new situation was to be considered. Therefor in the last phase a simulator was employed which could create very large numbers of situations simply by using menus in a computer program; no programming would be required of experimenters. Likewise, in the second phase we sought to avoid construction of a new computer program for each simulated situation. So development of simulation language, ICARUS, was undertaken. As will be clear, this phase of this project was very ambitious.

ICARUS is a language for studying the response of groups of intelligent people to crisis situations and the evolution of their organization over time. The ICARUS language allows the people, decision rules, and constraints of a crisis situation to be described, and the description is used to produce a trace of the unfolding of events as the people interact with each other and their simulated environment. ICARUS is a tentative first step in using computers to model such human interactions. We fully expected the heat of the sun to melt the wax holding the entire structure together.[37]

General Framework Of Icarus

The Ada programming language was selected as the foundation for ICARUS. Among its many advantages, Ada is suitable for large scale simulations, highly portable, and is supported by DARPA - STARS's reuse library system, ASSET. In addition, simulations written in Pascal can be readily translated in to Ada.

To satisfy the requirements of the project a combination of computer simulation and expert system features needed to be incorporated. Activities of individuals operating in decentralized decision making environments require the expert systems approach. The complex nature of environments in which organizational decision making takes place, and the equally complex characterizations of key organizational variables (such as communications networks' shapes, reliabilities, utilization and modification) require advanced computer simulation techniques. A discrete event simulation is appropriate for these purposes.

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observed in prior studies. Moreover, some have successfully predicted the behavior of subjects in later experiments. Appendix 2 lists some typical simulations at each level of behavior.

[37] As is usual with computer systems, however, the name ICARUS could be interpreted as an acronym, the Iowa Crisis And Response User Simulation.

Traditional expert systems normally consist of two components, a database and an inference engine containing a set of rules. The first contains an individual's knowledge and the second uses that to generate responses to new data. Knowledge may include not only awareness of the current state of the organization, but who knows or believes various characterizations of the current situation. The decision rules can also be quite complex, for example telling simulated participants how to decide who to tell what information to and when.

Discrete event simulation requires that a system be characterized as a finite state. For example, a finite state would specify each person's current knowledge as well as her current morale and stress. Knowledge would be about the organization's environment and current condition, others' preferences/priorities, knowledge, and premises, one's own performance, and the likely consequences of alternative responses the existing situation. In addition, discrete event simulation provides for instantaneous changes in states, that is events. They can include acts like communication and/or distortion of information, choices, restructuring network, and the loss of an organizational unit. Discrete event simulators can also arrange to have a history of events programmed to affect future events.

An ICARUS model consists of the following components:[38] A set of variables, a geographic model, and a list of people. The variables describe observable features of the real world. People may observe the values of variables, people may change variables, and people may hold possibly conflicting beliefs about variables.

The geographic model describes the places where people may go. At any instant, each person is in some place, and one of the actions people may take is to move to another place. Geographic constraints determine how long it takes to get from one place to another, and they determine which moves are legal.

Each person in an ICARUS model has a place, a set of beliefs about the variables of the model, and a set of rules that relate those beliefs to the actions a person may take. The actions a simulated person may take include inspecting the actual value of a variable, speaking a belief about a variable, changing a belief about a variable, and moving to a different place.

For the purpose of examining the results of simulation, an ICARUS person may also print out a note in the simulation output. In addition, there is a trace option to make the output include all actions taken by an ICARUS person.

A Very Very Simple Example[39]

[38] More detail about these components can be found in Appendix 7.

[39] It is extremely important to keep in mind that, when complete, the Icarus language will support vastly more complex situations and decision systems than these simple examples would seem to imply. By working with simple examples we have been able to discover and solve critical problems which would be much more difficult to find and understand with more complex examples.

Although the ICARUS project was motivated by complex crises like United 232's (flight which crash landed in Sioux City, IA) in which intelligent people collaborate to overcome extreme crisis, the development strategy for ICARUS was incremental. The following graduated sequence of examples suggests the procedure used to develop and refine ICARUS. The strategy was to build simple models using different approaches to the relationship between the parameters of the model and the likelihood of successful outcome. Once a simple model exhausted it's ability to help improve ICARUS it was discarded. The examples introduce the ICARUS language and should give some hint of its possible applications.[40]

Consider a world with two rooms, call them Here and There. The following ICARUS model describes the behavior of Fred, a fairly stupid fellow with no beliefs who spends his life shuttling from here to there:

```
GEOGRAPHY
   Here
      There 0:3
   There
      Here 0:4
PEOPLE
   Fred
      PLACE = Here
      RULES
         PLACE = Here -> SET PLACE = There
         PLACE = There -> SET PLACE = Here
      END
END
```

Throughout this model, indenting is used to show the relationship between the parts of the model. For example, the place names Here and There are indented an equal distance under the keyword GEOGRAPHY. Under each of place name in the GEOGRAPHY section is a list of the places that can be reached from that place. For example, from Here, you can get to There in three minutes, and from There, you can get to Here in four minutes.

There is only one person in the list of people, Fred. The indented list under Fred is a list of his attributes, including his initial place and his list of rules.

Fred's rule list is fairly simple. If he finds himself in the place called Here, he moves to the place called There, a move that will take three minutes. Similarly, if he finds himself in There, he moves back to Here.

[40] The ICARUS Reference Manual may be obtained upon request to the author.

This isn't a very interesting model for a number of reasons. First, if it is used as input to ICARUS, there will be no output. This is because there is no request to trace all of the actions of Fred, and because none of Fred's rules ask for any output. The second shortcoming is that the model never terminates; Fred will shuttle between Here and There forever. Finally, of course, the model is fundamentally uninteresting because nothing of consequence ever happens to Fred in his mindless shuffle between Here and There.

A Very Simple Example

In the next example, our simulated person Fred has a more complex problem to solve; he must navigate from Here to There through a connecting room called Nowhere. In addition, we will make the model terminate, and we will make it output a trace of all actions taken by Fred.

```
VARIABLES
   Goal = Nowhere
GEOGRAPHY
   Olympus
   Here
      Nowhere 0:1
   Nowhere
      Here 0:1
      There 0:2
   There
      Nowhere 0:3
PEOPLE
   Chronos
      PLACE = Olympus
      RULES
         -> DELAY = 0:20:30 TERMINATE
      END
   Fred
      TRACE
      PLACE = Here
      BELIEFS
         Goal = There
      RULES
         Goal = 'There AND NOT PLACE = There -> SET PLACE = There
         PLACE = There -> BELIEVE Goal = 'Here
         Goal = 'Here AND NOT PLACE = Here -> SET PLACE = Here
         PLACE = Here -> BELIEVE Goal = 'There
      END
END
```

This model terminates because there is a person named Chronos in a place called Olympus who's only role is to end the simulation after twenty minutes and thirty seconds. The only reason for the place called Olympus is to provide a place for Chronos to work from. Olympus is an unreachable place, and Chronos doesn't interact in any way with Fred.

In more interesting models, the occupants of Olympus can be given more work to do. For example, they can force a variety of trials on the simulated people by abruptly changing the values of variables, and they can be used to enforce the "rules of nature" by adjusting the values of variables in response to actions taken by the simulated people.

The geography of this model now has a place called Nowhere which is between Here and There. The total distance from Here to There is still three minutes, and the total distance from There to Here is still four minutes. Now, however, there is no direct path from one to another. If Fred finds himself in Nowhere, there are two places he could go next. In order to preserve the pattern of behavior from the previous model, Fred needs to remember his goal as he enters Nowhere so he can know which exit to take. To allow for this very simple mental state, we introduce the variable called Goal; Fred's mental state is represented by his belief about this variable. Fred never actually looks at the value of the variable, but we need to set the value so he can have a well defined goal.

Fred's rules in this model can be paraphrased as follows: If Fred's goal is There and he finds himself not to be There, then he tries to move There. On arriving There, he sets his personal belief about his goal to Here. Another rule will then drive him to Here, at which point, he sets his goal to There. The order in which these rules are stated is irrelevant.

Note that Fred's rules never mention the intermediate place called Nowhere. If he is Here, his attempt to get himself to There will land him in Nowhere, at which point, he will find that he is not yet There, so he will try again to get There.

It is worth noting the role of the apostrophes in the above code. These are used as prefixes on the symbols Here and There when these are being assigned to or compared with the values of variables. The apostrophe is used to distinguish syntactically between constants and variable names.

Finally, the keyword TRACE under Fred's name is what causes the simulation to produce output. When the simulation is run, the following output is the result:

```
 Time    Person Action
 ====    ====== ======

0:01:00.00, Fred moves to: Nowhere
0:03:00.00, Fred moves to: There
```

0:03:00.00, Fred believes: Goal = Here
0:06:00.00, Fred moves to: Nowhere
0:07:00.00, Fred moves to: Here
0:07:00.00, Fred believes: Goal = There
0:08:00.00, Fred moves to: Nowhere
0:10:00.00, Fred moves to: There
0:10:00.00, Fred believes: Goal = Here
0:13:00.00, Fred moves to: Nowhere
0:14:00.00, Fred moves to: Here
0:14:00.00, Fred believes: Goal = There
0:15:00.00, Fred moves to: Nowhere
0:17:00.00, Fred moves to: There
0:17:00.00, Fred believes: Goal = Here
0:20:00.00, Fred moves to: Nowhere

0:20:30.00, Chronos terminates simulation.

Fred's beliefs at termination are:

Goal = Here

:

The trace of activities is intended to be subject to automated analysis. It consists of a series of lines, where each line reports one action --

at TIME, PERSON said VARIABLE = VALUE
at TIME, PERSON moved to PLACE
at TIME, PERSON set VARIABLE = VALUE
at TIME, PERSON believed VARIABLE = VALUE
at TIME, PERSON printed NOTE

Technical Considerations

The rules governing a simulated person are only evaluated when that person is alerted. The initial alert for an ICARUS person occurs at the beginning of time. After that point, the person alerts himself every time his beliefs change, and he is alerted by changes in his environment. In the above example, for example, he alerts himself when he enters a new place. Although it is not illustrated above, an ICARUS person will also be alerted when someone in the same place speaks, when a new person enters the place, and when an alarm goes off.

Each rule consists of two parts, a guard and an action. These are separated by the implication arrow "->". If a guard is found to be true when a person is alerted, then that rule is said to fire and the resulting action is scheduled. An empty guard is always considered to be true.

When a rule fires, the action need not happen immediately; for example, moving from one place to another takes a simulated time proportional to the delay indicated in the

GEOGRAPHY section. Additional delay can be specified for any action with a DELAY clause, as used in the above example to control the time limit that Chronos imposes on the model.

Time is input and output in units of hours, minutes, and seconds (with an optional fractional part indicating hundredths of a second). The notation used is conventional, with colons separating the fields.

A Simple Example

Building on the above model, where Fred wanders back and forth between Here and There, we can give Fred a job to do. Consider the following. In Here is a meter showing the level of the water in a reservoir. In there is the control lever for the outflow. Fred must try to hold the water level at some set point. To model this, we need a physical model:

    Flow = Inflow - Outflow

The total flow in or out of the reservoir is equal to the difference between the flows in and out of the reservoir. Flow can be measured in cubic meters per second.

    dLevel/dt = Flow / Area

The rate of change in the level of the water increases with increased flow and it decreases with increased reservoir area.

    Outflow = Level * Valve

The flow out of the reservoir increases as the drain valve is opened, and it increases as the water pressure increases. The constant of proportionality is one if the valve opening is measured as the number of cubic meters per second that flows when the reservoir is one meter deep.

The model will use a discrete approximation of this system, where Neptune, another occupant of Olympus, manages the rise and fall of the waters in response to the current inflow and valve settings.

```
VARIABLES
   Valve  = 0.0  -- the setting of the drain valve (closed)
   Level  = 0.0  -- the water level, in meters
   Inflow = 1.0  -- the rate of water flow in, in cubic meters/second
   Area   = 10.0 -- the area of the reservoir (a constant)

   Goal = Nowhere

GEOGRAPHY
```

```
   Olympus
   Here
      Nowhere 0:1
   Nowhere
      Here 0:1
      There 0:2
   There
      Nowhere 0:3
PEOPLE
   Chronos
      PLACE = Olympus
      RULES
         -> DELAY = 0:20:30 TERMINATE
      END

   Neptune
      PLACE = Olympus
      RULES
         -> DELAY = 0:0:1 SET Level = OBSERVE Level +
                          (OBSERVE Area *
                          (OBSERVE Inflow -
                          (OBSERVE Valve * OBSERVE Level)))
         -> DELAY = 0:0:1 ALERT
      END

   Fred
      TRACE
      PLACE = Here
      BELIEFS
         Goal = There
         Level = 0.0
      RULES
         Goal = 'There AND NOT PLACE = There -> SET PLACE = There
         PLACE = There -> BELIEVE Goal = 'Here
         Goal = 'Here AND NOT PLACE = Here -> SET PLACE = Here
         PLACE = Here -> BELIEVE Goal = 'There

         PLACE = Here -> BELIEVE Level = OBSERVE Level
         PLACE = There -> (
            Level < 5 -> SET Valve = OBSERVE Valve + 0.1
            Level > 6 AND OBSERVE Valve > 0.0 ->
                      SET Valve = OBSERVE Valve - 0.1)
      END
END
```

In this model, Neptune has two rules. One rule causes him to alert himself every second. When he is alerted, he reevaluates all of his rules. The other rule models the laws of hydraulics as they apply to the reservoir problem.

Fred has two new rules, one of which applies if he is Here, and the other of which applies if he is There. When he is Here, he updates his belief about the level of the reservoir. When he is There, he either opens the valve a bit, closes it a bit, or leaves it alone.

Note that in these rules, there is a clear distinction between a person's beliefs about a variable and the actual value of the variable. Beliefs are set with the BELIEVE keyword, while the SET keyword changes the actual values. The keyword OBSERVE is used to check the actual value of a variable, while variable names that are not qualified refer to the person's belief.

Modified versions of this example almost work, but CHRONOS currently goes mad with his job of enforcing the laws of nature.

Some Limitations of Icarus

ICARUS has a number of additional weaknesses. The above examples illustrate some of these.[41] However, the most important weakness is that, in attempting to describe a system involving both people and a physical system, two different approaches to simulation are required, expert systems and discrete event simulation. Discrete event simulation is an established technique for modeling systems with strict attention to temporal constraints like those experienced in crises. It is commonly used in areas such as logistics models. While expert systems show great promise for modeling intelligent decision making, our attempt to incorporate expert systems into discrete event models in ICARUS has demonstrated that fundamental problems arise when the two approaches are combined. Previous work involved either strong simulation methods combined with weak expert systems, or the converse, as in Saso (Novick, 1990). These weak combinations did not reveal the fundamental problem which arises when both approaches must contribute equally. The project demonstrated that, although ICARUS supports an event-centered model of the world, a model which may be reasonably well suited to modeling human decision making, it is clearly poorly suited to models of continuous processes such as the filling and draining of a reservoir. Despite numerous attempts we failed to learn how to better integrate these two kinds of models satisfactorily.

A number of quite critical features were not developed as a result of the time consumed trying to solve this fundamental problem. For example, although it is not apparent in

[41] In discussing ICARUS weaknesses, it should be noted that the current ICARUS implementation is so fragile that slight variations on a working model frequently fail to work properly. This discussion focuses on the underlying weaknesses of the ICARUS language itself and does not focus on the inadequacies of the current implementation

any of the simple examples given here, ICARUS people are very credulous. No matter how complex their rule base, they always believe everything they are told. Clearly, it is necessary to find a way to add a class of rules that determines how a simulated person interprets what they are told, with interpretations based on what they believe and on who is saying what.

There are also many minor annoyances in the ICARUS language which would need to be resolved once the major problem is resolved and additional critical features are successfully added. For example, it is annoying to have to list all subjects about which a person may have a belief as model variables. Some such subjects are purely local to one person, for example, a person's goals. We need a way to let a person have such private beliefs. Another minor annoyance is the need to initialize the value of every belief. All variables have initial values, and it would be nice if the default initial value of a belief was an accurate reflection of the initial value of the corresponding variable.

Conclusions from Phase 2

Struggling with ICARUS challenges consumed far more time during Phase 2 (and in to subsequent years) than had been anticipated. Ultimately it was concluded that the effort was far too ambitious. If the ICARUS initiative is to progress beyond this point, the kinds of resources devoted to the construction of SIMNET (Alluisi, 1991; Miller and Thorpe, 1995) will be required. For now it appears that simulation approaches satisfying the purposes of this project will, if possible, need to adapt SIMNET or its successors as they become available for nonmilitary uses.

Work with ICARUS reinforced the conclusion that many, if not most, of the central linkages and interactions affecting how well organizations balance routine efficiencies and crisis readiness remain matters of speculation more than scientific theory or findings. As would be expected given the results of the Phase 1 macro analyses, most ICARUS design options had to be resolved by judgments rather than by relying on evidence from studies. Theoretical guidance was also limited because so few theories address intra-organizational phenomena.

Due to the persistent challenges posed by ICARUS, the third phase of the project was forced to develop experiments without the anticipated guidance of results from ICARUS-based simulations.

Simulators as Research Beds

In the last decade attempts to achieve rigorous tests of causal propositions in complex settings has led researchers to increasingly rely on simulators.[42] They have been encouraged to do so by several factors. Among the most important is the fact that organizations are increasingly relying on distributed decision making systems in which

[42] At least seven simulators have been used in experiments on distributed decision making. For a review see Weaver, et al., (1995).

many organizational members make semi-autonomous judgments and choices and there is a premium on adequate coordination of those decisions. These systems, like simulators, require that communications be conducted over electronic media rather than face to face. A second major factor encourage use of simulators is advances in computer capabilities, particularly capabilities created by linking personal computers in local area networks. A third factor is rapidly falling costs of computer equipment. A fourth consideration is participants' accelerating familiarity with, and interest in, computer-based tasks (including computer games).

Simulators are usually designed with specific research hypotheses in mind. For example, just as Carley, et al., (1992) extended SOAR (Laird, et al., 1987) from a focus on individual to multi-person) cognition processes in their PLURAL SOAR simulation, TIDE[2] (Hollenbeck, et al., 1995) was developed to extend Brunswick's (1955) lens model paradigm for individual judgment to distributed decision maker's assessments in hierarchical command and control situations. C.I.T.I.E.S. is an experimental vehicle designed to learn how two interdependent teams learn to recognize the nature of civic emergencies (Wellens and Ergener, 1988). Because the main goal of the present project was to improve understanding of organizational decision processes, an organizational simulator, ALCO, was employed as an experimental test bed.

ALCO

ALCO was created at the University of Iowa from 1985 to 1987 relying on proprietary hardware and software from UNISYS. From 1990 through 1993 it was refined, converted to Turbo Pascal in a DOS IBM personal computer, local area network environment, and transported to other universities.[43]

Comparisons of ALCO to Other Simulators

In some respects ALCO resembles SYNWORK1 (Elsmore, 1994). Both are "man in the loop" simulators which require effective individual performance by human participants. To achieve effective performance both require monitoring complex activities, arithmetic reasoning, and memory. Both provide feedback and the difficulty of tasks can be varied in both simulators. However, SYNWORK1 was not designed for exploring group performance; unlike ALCO it focuses on individual skills and performance under trying conditions (such as in sleep deprivation research).

As noted previously, ALCO, unlike ICARUS, DISCUSS (Stasser, 1981, 1988), PLURAL SOAR, and ELM (Carley, 1991; Carley and Prietula, 1994), is a "man in the loop" organizational simulator rather than a pure simulation model lacking actual human inputs to the system.. Like many simulations (e.g., the Garbage Can models of Cohen, March, and Olsen, 1972; Anderson and Fischer, 1986; Carley, 1986; Masuch, and LaPotin, 1989), ALCO is concerned with issues of organizational performance and

[43] The ALCO programs and Manual can be obtained from the author. However, technical support is very limited.

adaptation. Unlike the Garbage Can models, and like ELM, ALCO incorporates individual, as well as organizational and environmental, variables.

ALCO was inspired by many of the same considerations that led to the development of Distributed Interactive Simulation - DIS standards (Fletcher, 1994; Fitzsimmons and Fletcher, 1995), SIMNET (Alluisi, 1991; Miller and Thorpe, 1995) and TIDE^2 (Hollenbeck, at al., 1995). For example, all three simulators require at least two human actors to make numerous decisions of many kinds. However, unlike DIS, whose applications emphasize training, ALCO and TIDE^2 were motivated by the desire to conduct research capable of strong inference about the systemic effects of distributed decision makers, distributed and imperfect information, changes in communications links' structures and quality, and numerous other properties of real organizations on decision processes and their outcomes (such as accuracy, satisfaction, cohesion, and learning).[44] ALCO is adaptable to tactical military applications (DIS) or military command and control (e.g., TIDE$^{2)}$ settings but it is not limited to military contexts. All three simulators emphasize coordination of autonomous agents who must achieve success in complex environments to survive. Unlike TIDE^2, both DIS and ALCO require shared views among agents to achieve this coordination. Both TIDE^2 and ALCO provide each agent with unique environmental data, but ALCO and DIS often provide overlapping data as well. Unlike TIDE^2 and DIS, ALCO does not emphasize geographic information as it was not developed to simulate battlefield task conditions (although it can use battlefield interpretations of its parameters).

ALCO Decision Tasks

A central feature of work group and organizational life, one not included in most simulations or simulators (e.g., Tide^2), is that many roles are required of each participant. In the context of distributed decision making, most members must be capable of making decisions which can be defined by many task typologies. Both unitary (where judgments must be made by all members acting as a whole - Laughlin and Branch, 1972) and divisible (where each member can make separate judgments which contribute to collective performance) are frequently encountered. Both simple and complex judgments (Shaw, 1964) are required. At times disjunctive decisions (where collective performance hinges on the resources and performance of the most competent member - Steiner, 1972) are required. Other situations are conjunctive (performance hinging on the poorest individual judgments or decisions). Yet others are additive (each member's assessments or choices are summed in some fashion). Some stages of a decision process emphasize creativity, others logical ability, and still others social persuasion or meshing of personalities (Driskell et al., 1989). Some problem solving situations are of the "eureka" type, where the solution or answer is inescapably optimal; but most decisions contain options that cannot be so clearly distinguished in terms of their relative merit. Some decisions occur where members share mental

[44] Of course ALCO, like DIS, can be used for training. However, ALCO was intended primarily to train administrators (managers and executives) rather than battlefield commanders.

models of the situation and/or shared judgment policies. Other decisions arise in contexts of cognitive conflict (Rohrbaugh, 1979) or dissimilar images of the situation.

Crises can be created using a variety of ALCO options. A few are noted here. One is to degrade communications by replacing some proportion (selected by the experimenter) of message contents with random symbols. Another is to change the relative importance of each member's performance frequently and/or radically. A third is to provide too many sources of information, creating potential information overload. Or communications structures and/or decision processes can be manipulated to allocate excessive work for some members and little for others. Or the level of performance (e.g., accuracy in team estimates) required to receive (any given level of) new resources may be suddenly raised, as when an organization's environment suddenly becomes more hostile. One of the most salient ways to effect a crisis is to impose very high penalties on participants for the time they consume to perform their many tasks.

ALCO is designed to permit a greater variety of decision task types to be explored than most simulators. For example, whereas TIDE^2 employs only a divisible task, ALCO can use both divisible and unitary decision tasks. Whereas TIDE^2 requires each member to only make judgments, ALCO requires both judgments and arithmetic tasks to be performed. ALCO can confront members with additive or non-additive tasks. ALCO tasks can be made to be conjunctive, disjunctive or additive and can vary this attribute for each trial if so desired. Most importantly, ALCO members can be given the ability to reconfigure their organizational structures and processes, unlike TIDE^2, DISCUSS, and most other simulators.

ALCO's basic decision tasks are of two kinds, explicit and implicit. Both kinds of tasks must be performed individually by each member as well as collectively through dialogs. As will be discussed shortly, there are two major implicit tasks, assessing covariations, and judging the probable value of alternative organizational arrangements. These tasks are performed within the confines of several organizational systems. Among the most important are the communications network, decision making system, resource allocation system (as in budgeting), and (potential) impact system.[45] Depending on the experimental question, the organizational systems themselves may be, at least partially, under the team's control.

The impact system reflects the importance of each member's personal performance to the organization. In ALCO, as in most organizations, some members' performances are usually more critical to the organization's performance than are other members' performances. Also, as in many organizations, the relative importance of each member's performance may change over time as conditions change. Over trials an experimenter may create any desired impact structure. For example, all members may

[45] These structures may or may not be aligned. For example, a member who has power because of a central position in the communications network may have few of the resources needed to acquire adequate information, change the network, or communicate clearly over existing channels.

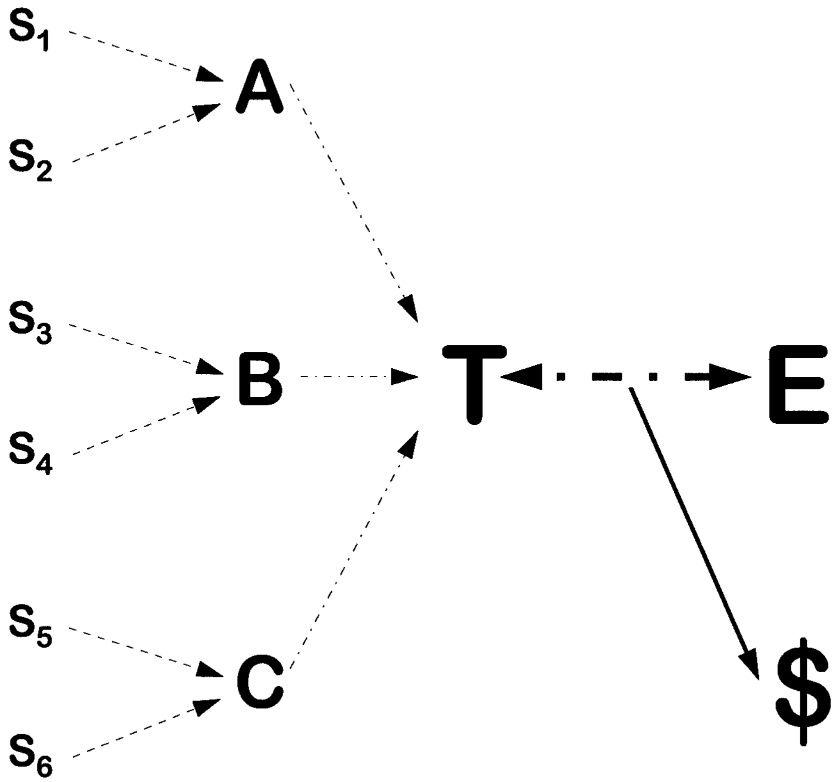
initially be equally vital, but some members become more vital than others over time. Each member's impact is implemented by using an equation known to all participants. The equation weights each unique parameter's current value to determine each member's impact (and to establish the team's best possible estimate).[46] ALCO's communications and decision system characteristics will be easier to understand once the decision making tasks members must perform are more fully described.

ALCO teams or organizations may have as many as 12 members.[47] The two major explicit tasks are to formulate individual and collective estimates of several parameters' current values. First, each member must formulate an estimate about the current value of a parameter which is the unique responsibility of the member. Then, once each member has formulated a judgment about his or her unique parameter's current value, the members must formulate a collective estimate or forecast using the estimated values of their unique parameters as effectively as possible.

Each member (A, B, and C in Figure 1 below) has one or more potentially perfect information sources (S_1 through S_6) or advisors which can be consulted. One of the implicit decision tasks for each member is to determine how much of their available resources should be devoted to obtaining advice or information. The experimenter determines how tightly coupled are the source's accuracy and the resources provided for the information or advice. The linkage may be very tight for some sources and very loose for others, varying continuously in whatever manner the experimenter or trainer elects. Thus, one of the first important implicit decision tasks involves making judgments about covariation between a given source's accuracy and the amount of resources to be "paid" for the source's information or advice. This particular task can be made to be extremely challenging if the experimenter elects to vary the actual amount of linkage between resource "fee" and source accuracy over trials. Additional implicit covariation judgment tasks also arise with respect to the collective judgments. These are described shortly.

[46] Thus, in a three member team if the unique parameters for members A, B and C were weighted 0, 2 and 4 respectively, C's impact would be twice B's and A would have no impact. In addition, the best team estimate would be the sum of twice A's parameter's current value and four times B's parameter's value.
[47] For logistical and statistical reasons three person teams were used in this project.

Figure 1
Basic ALCO Task



Where:

S_1 through S_6 are advisors or information sources which suggest the current values of A, B, and C respectively,

A, B and C are team members' estimates of three different parameters,

T is the team's estimate of an environmental parameter's value which is a function of the true values of A, B, and C,

E is the current environmental parameter's value, and

$ is the payoff, replenishment of resources, generated by the accuracy of the team's estimate.

Numerous interpretations of the explicit decision tasks can be used. For example, in a civil defense instantation of ALCO, on each trial one member could be required to estimate an incoming missile's speed based on the estimates received from radar and a satellite. Another might estimate the missile's direction of travel based upon a ground report from a forward observer and the satellite. A third member might estimate the missile's warhead size based on intelligence estimates. The first implicit covariation tasks are for each member to decide the amount of resources to expend for indicators, which indicators are most effective (in terms of accuracy provided relative to resources consumed), and whether or not to "purchase" additional data from any of the available indicators. The experimenter can control the number of indicators available to each participant, whether or not participants share any indicator(s), and the degree of accuracy each indicator will provide for a given expenditure of resources.

To continue the civil defense example, the team's second explicit task is to formulate a team judgment or estimate (T in Figure 1). In the example it could be to estimate the

risk to the civilian population, in terms of probable numbers of lives lost, based on the members' estimates of speed, direction and warhead size of the missile. To achieve the best possible team estimate (E in Figure 1) each member's unique parameter must be assessed with perfect accuracy, then those values must be aggregated employing the function specified for that trial. The more accurate the members' collective (team) estimate of losses (T) the more effectively the population can be protected, hence the more replenishment of resources ($ in Figure 1) available to the team.

Two implicit covariation judgments are useful at this point. One is for members to assess how tightly linked are accuracy of team judgment and the amount of subsequent replenishment. In formulating this judgment, members are forming impressions of their environment's munificence - the amount of replenishment likely to be obtained for any given level of accuracy. The other implicit covariation task arises when any replenishment of resources is distributed to individual members rather than being retained in a central pool. In such cases an experimenter may have elected to base distributions on a (moving) average of the members' individual decision performance, as in a meritocracy, divide replenishments equally among members, or maintain a specified allocation (that could favor some members over others irrespective of criteria related to the members' behaviors). Thus, each member faces an implicit task of judging how well rewarded is high quality individual decision making, yet another covariation assessment.

Numerous judgments must be made in each trial. Not only must each participant decide how much, if any, to spend for information or advice, but they must also decide: whether to accept or revise the recommended estimates they obtain from their sources, the reasons for their personal and the teams' performance in previous periods, whether it would be appropriate to ask others for information and/or resources and/or help, if they should interrupt their current activities to respond to others, the potential value of checking on others' past behaviors, if it is necessary to open new channels of communication, and when to suggest changes in procedures or team estimates. And these are but a few of the choices, judgments and forecasts involved in every period.

Recall that the second important, but implicit, ALCO decision task is to assess the probable value of alternative organizational processes and systems.[48] Irrespective of the decision system (e.g., dictator, majority, consensus, etc.) required by the experimenter, important but implicit communication decisions are required. Two major, often necessary, implicit communications decisions involve network structure and message redundancy.

Structural changes in networks can arise in two ways. Some links may fall in to disuse or never be used at all.[49] Or, links may be added. For example, frequently an experimenter will prescribe a communications structure among members (such as the

[48] Only some of the major organizational issues involving communications structures and processes will be discussed here to avoid unnecessary complexity.
[49] This is common when members in "all channel" networks have simple or routine tasks.

classic wheel or chain, Shaw, 1964) and give one or more members the ability to add links. Usually links can be added only by consuming resources, and not all links "cost" the same amounts. Thus, some member(s) must judge which new links, if any, would be cost effective. Where two or more members with individual resources can add the same link, possible conflicts of interest may arise as each waits for the other to act in order to save their personal resources. Thus, ALCO can create free ridership dilemmas for teams to resolve if they are to achieve adequate performance (Dawes et al., 1986; Samuelson and Messick, 1986).

Redundancy in the content of messages can be helpful because each ALCO link may conduct information imperfectly, some links more so than others, and the amount of a link's imperfection may be varied over trials in a planned manner.[50] Where noise, in the form of random symbols replacing letters or numbers, is present one or more of the members may be authorized by the experimenter to use resources to increase a link's fidelity. If none of the members have that ability, or those that do have it elect not to use it, "noise" in a link may cause delay or misinterpretation of messages. Two additional ways to overcome low fidelity, which teams may not discover, are to introduce codes and/or increase redundancies within a message. Thus, ALCO challenges members' ability to innovate. This challenge is of greatest importance in the kinds of communications crises studied in this project, where delays in innovation can cripple collective decision making.

In some ALCO setups members may elect to alter their decision processes. For example, teams required to achieve unanimity may decide to designate one member to determine the team's estimate and then communicate that value to every other member so that it becomes every member's estimate. If so, the team's decision system is effectively a "dictatorship." More often, when using decision systems like majority vote, consensus, and plurality, each member communicates - to whatever other members they can, or elect to, address - a personal estimate of their unique parameter's value, and (later) their individual recommendation for the team's estimate (e.g., of the number of lives likely to be lost).

It is to be expected that organizational properties will often have interactive effects. For example, the current communications structure and decision rule both affect the number and routing of messages flowing through the network as well as each member's workload. Dictatorship usually results in fewer messages but centralizes the information processing in one member whereas consensus distributes more data through more messages but permits debate and other forms of decentralization in the team's decision process. Of course there are likely to be asymmetries. In a consensus decision system members are free to reallocate aspects of the decision task to a greater extent than is possible in a dictator decision system.

ALCO Variables

[50] Noise in a channel can be varied from none to 100 percent at the experimenter's discretion.

ALCO permits quick and easy implementation of experimental designs (or training situations) that confront participants with tasks whose nature cannot be easily anticipated from trial to trial. Over three dozen independent variables, (such as the cost of establishing each one way communications link, the degree to which each member's own resources devoted to search are linked to quality of information produced by search, and the initial or possible communications networks) can be manipulated using a series of menus.[51] As has been suggested, the major sets of independent variables are resources (such as individual funds and personal advisors for each member), rewards (for each member or for the team or organization), communications, feedback, performance evaluation, and decision scheme or system (e.g., dictator, plurality, consensus).

Most of the independent variables can be used not only as inter-organizational manipulations, but as intra-organizational manipulations as well. One example of the latter is the distribution of replenishments over trials. Others include the distribution of members' impact, the quality of data flowing through each communication link, the utility of information a decision maker obtains from his or her sources, and the availability of any one source's information to each member.

More than twenty dependent measures are automatically recorded. They include such resource choices as amount used by each member for acquiring advice, creating additional communications links, and giving subsidies to other members or units. Each member's judgmental accuracy and the accuracy of the team's estimate are recorded. Communications dependent measures include the network structure at each moment, intensity of channel usage (each way in a link), timing of message transmissions, and contents of each message. Performance dependent measures (including time and resources consumed, length of subunit and/or organizational lifetimes, individual judgment accuracy, efficiency of team performance) are obtained for individuals or subunits as well as for the overall organization. All recorded data are time stamped to permit calculations of latencies and lags.

In effect ALCO permits members of a simulated organization, acting in a strong induction (experimental) setting, to not only perform routine and adaptive tasks, but to change the very nature of their own organization at the same time. This is characteristic of the actions of experienced personnel like FAA controllers who redesign complex systems "on the fly" when emergencies arise (McKenna, 1991). If ALCO were a flight simulator the flight crew would be not only "flying the plane" and attending to emergencies, but redesigning the aircraft and/or crew responsibilities at the same time. For example, when a crisis arises because a communications link is unexpectedly lost participants must construct a remedy relying on several capabilities (e.g., re-routing via

[51] For a complete listing of ALCO variables see Appendix 8. Additional manipulations can be achieved using written or verbal directions that supplement ALCO's independent variables. For example, each team may be told it is in a tournament in which the members' pay for participating depends upon how well they perform compared to other teams.

more costly paths, greater reliance on standard operating procedures and terminology, decentralization) to retain adequate coordination.

There are many other features which make ALCO a useful experimental vehicle. The multiple tasks involve both social and organizational. Many of the variables which can be manipulated or measured are at the organizational rather than individual level. An extraordinary number of possible issues and designs can be easily created. Experimental sessions are more consistent over time because the subjects' situation is automated rather than subject to experimenter error. Sessions can be run on most existing local area computer networks, even if the computers are physically dispersed. Because the system is computerized, most participants become deeply involved.

There are several challenges posed for researchers when using ALCO. The first is learning how to use the system's two key programs which set up experiments and the third program which runs the network. Care must be taken to assure that the parameter values which are chosen are both internally consistent[52] and faithful implementations of theory, the conditions in other studies, or the values found in actual situations. Nonverbal communication and behaviors cannot be manipulated nor measured. Most relationships between variables have been specified in a linear manner as a first approximation to situations which may be nonlinear. Statistical power is expensive because each observation requires at least three adults working for up to six hours. Finally, each experimental session produces large quantities of data, challenging users to devise efficient data reduction techniques.

Based on all the materials which had been reviewed in Phase 1 of this project, it was determined that ALCO experiments should focus on stress, decision systems, and type of crisis facing the organization. The following section serves to review relevant studies on these topics. It also provides an example of a propositional inventory of the kind discussed in Phase 1.

Organizational Tasks, Structures and Decision Systems:

In the context of managing complex systems, Perrow (1984) noted an inherent contradiction faced by most organizations. Managers of complex systems must be both highly centralized (to coordinate actions) and highly decentralized (to react in timely fashion) when balancing routine and readiness. In organization theory it is virtually an axiom that organizations require different decision making structures to respond effectively to different environments and to routine versus non-routine situations (Duncan, 1973). Units in which effective performance requires members to sustain high performance in both individual and collective tasks are likely not to perform as well as those where tasks can be structured to consist of essentially autonomous individual activities or primarily collective activities (Wageman, 1995). Yet, as Perrow (1984) implied, in many contexts it is not possible to create and sustain such a neat division.

[52] The feasibility of different combinations of parameter settings can be estimated by constructing spreadsheet analogs to the experimental designs which are being considered.

When the same unit must conduct routine decision processes while constantly maintaining readiness to cope with crises, the cognitive capabilities of members are only one variable affecting performance. Another set of variables involve the relationships, exchanges, and interactions among members (Foushee, 1984; Foushee and Helmreich, 1987). The speed and accuracy with which changes in task requirements are noticed and interpreted depend on the nature of these variables. As one researcher noted,

> "[Team and o]rganizational structure is, among its other functions, a search heuristic. The quality of organizational search attained depends critically on the division of responsibility and attention among the organization's members, on the patterns of interactions among members.... In effect, the structure of the organization, its formal and informal channeling of interactions, and its biasing incentives, are a concrete heuristic for searching the vast space of logically possible policies [necessary for success]." (Cohen, 1982)

Complicating the analysis is the fact that organizations and groups have many structures, any one of which may dominate in a particular context. For example, in one context a member may be the most central person in the activated communications network, a marginal member in terms of status, and play an intermediate role in a decision scheme (e.g, an interpreter of data gathered by others who make suggestions to the ultimate decision maker. In another context the same member may be forced to act upon local information and only afterward inform others. Thus, structural factors both affect decision processes and are affected by previous decision activities.

Typically organizations respond to changes in their environments, shifts in the balance between routine and crises, new technologies, and turnover by altering one or more structures. For example, in an aerospace firm experiencing high morale but low productivity when everyone could freely communicate with everyone else, performance and satisfaction first fell, then rose, as communications were first centralized (in a wheel configuration) then decentralized (in the form of a circle - Mears, 1974). The result of attempts to reconcile all the forces affecting routine and adaptive performance is, in many cases, a sequence of structures which are neither well integrated nor suitable for many task situations. Referring to a mapping of communications linkages between 16 units used to make just one kind of decision, observers noted:

> "The irony, and the tragedy, is that each of the 223 linkages taken by itself makes perfectly good sense. Well-meaning, rational people designed each link for a reason that made sense at the time. The ... sad fact is that when we use this diagram in presentations, we don't draw shouts of 'Absurd.' Instead we draw sighs, [and] nervous laughter...." (Peters and Waterman, 1982).

It is little wonder that organizations evolve structures and procedures which are difficult to defend. Even in Carley and Prietula's (1994) relatively straightforward ELM simulation study, the best balancing of efficiency and readiness depended in a complicated manner on the relationship between the organization's information structure (how relevant information was initially distributed among members) and the

organization's decision making structure. Under comparable information conditions centralized decision systems never performed better than decentralized teams making collective decisions. However centralized decision structures performed more poorly in crises than did decentralized teams regardless of the distribution of information within the organization. When relevant information was given to all organizational members or when each relevant datum was unique to a single member (as in this experiment), both crisis and non-crisis performance was inferior to conditions in which subsets of relevant information was shared by various subsets of the organization's members.

Carley and Prietula simulations used a very simple decision task. Experimental research has usually found that when decision making or problem solving tasks are "complex," decentralized systems yield better results than centralized systems. For example, decentralized communications networks provided better responses to complex situations, crises and problems, and were more satisfying to members, than centralized networks. When tasks were simple, centralized networks were more efficient (Shaw, 1954a; Guetzkow and Simon, 1955; Shaw, 1964; Harshbarger, 1971; Snadowsky, 1972; Sypher, 1977). However, most experimental studies have, in fact, not really used very complex tasks. One that is frequently used is the common symbol task, using pure colors (e.g., of marbles) for simple conditions and blended colors for complex conditions. That is an extraordinarily simple task when compared to the complexity of decision tasks outside the laboratory.

The complexity of the decision task faced by actual decision makers can be extreme. Consider, for example, Xerox's decision about "the office of the future" - whether or not to initiate production of personal computers, laser printers, and local area networks before they were even considered by other firms (Smith, 1988). The radically new technologies (most of which were very different from familiar copier technology), magnitude of resources, uncertainty about market demand, personal ambitions, clashes of managerial and scientific cultures, and the distance between Rochester and Palo Alto were only a few complications. Complexity is even more an issue when decision makers are attempting to make sense of crises like forest fires (Mclean, 1992), managing leaks from nuclear power plants (Perrow, 1984), coping with reactions to product tampering, or assessing the intentions of approaching aircraft (US Congress House and Senate Committees, 1988 and 1993; Rogers, 1992).

Task complexity in these kinds of decision situations can result from many causes: the number of elements which must be integrated, their dispersion (among people, geographically, or over time), their novelty, demands for immediate but unproved responses, and numerous other factors. Thus, in a real world context, it is apparent that (even maximum) complexity in most experimental tasks is minimal. As such, the following summery may substantially underestimate, or even misrepresent, the true relationship between task complexity and organizational or group structure.

Relationships between structure and decision processes may not be so straightforward (Wood, 1973) as have been suggested by experiments. And, over time, they may be inconsequential. For example, in one study differences in performance due to different

structures of communications networks declined with experience and were virtually eliminated with appropriate reinforcement (Burgess, 1968). One researcher found that whether or not network structures are congruent with members' status levels may affect performance and satisfaction as much as the match between task complexity and communications structure (Moore, et al., 1972). In a recent study of reactions to complex situations it was reported that decision quality was unaffected by centralization, threat, extent of emphasis on the importance of accuracy, or perceived time pressure (Turner, 1992).

Task performance requirements are likely to affect communications patterns, and other indices of structure or process within units. There is experimental evidence that centralization of decision making, control, and communications is likely to be affected by many variables which define task complexity. Among them are the amount of tension (Staw, et al., 1981) or uncertainty (Bourgeois, et al., 1978) felt by members, the distribution of information among participants (Shaw, 1954), the power or status distribution of members (e.g., Hurwitz, et al., 1989), and the available technology (Siegel, et al., 1986). As noted below, tension or stress is likely to arise from uncertainty (Cohen, 1959), time pressure, threats, work or information overloads, and contagion of others' fears, among many possible sources.

Surprisingly, one recent experiment found that groups in a high-uncertainty, low-threat condition expressed the greatest amount of tension and developed the greatest degree of centralization (Argote, et al., 1989). One would have expected tension and centralization to be greatest under the high-uncertain and high threat condition. The sensation of tension or stress under high uncertainty is consistent with the threat-rigidity thesis (Staw, et al., 1981) and the widely accepted view that communications (Kano, 1977), decision making, and control become more centralized in crisis or stressful conditions (Hetzler, 1940; Janis, 1954; Korton, 1962; Herman, 1963; Holsti, 1971; Smart and Vertinsky, 1977; Milburn, et al., 1983).

Consistent with the threat-rigidity thesis (Staw, et al. 1981), one survey of managers and executives who had been confronted with an international financial crisis found that the more unmanageable the situation appeared to be the greater was the centralization of the firm's control system, and the poorer were attitudes (Kuklan, 1988). Similarly, some observations of flight crew communications in stressful or crisis conditions also support the threat-rigidity thesis. Subordinates more often withhold information or refrain from questioning orders or observations from superiors when under stress (Foushee and Helmreich, 1988). And they are more willing to acquiesce to superiors (Hamblin, 1958; Klein, 1976; Worchel, et al., 1977; Driskell and Salas, 1991a).

Other studies, however, indicate these patterns may not be very general. One suggests that stress causes both high and low status members to become more receptive to messages from other members (Lanzetta, 1955; Torrance, 1967; Driskell and Salas, 1991a), more equal participation in decision processes (Lanzetta, 1995), and more solicitation of subordinate opinions by superiors (Torrance, 1967). Another study reported that increased time pressure did not cause influence to shift upward

despite increased stress. Information processing by the group did fall (Gladstein and Reilly, 1985). Thus, in general, the evidence fails to conclusively support the "threat-rigidity," or centralization arguments as generally valid propositions.

Facing these cross currents of arguments and evidence, many would agree with Vroom (1973) that there are situations where a leader must decide, perhaps after consultation with group members, and other situations where (at least) a majority of the group's members should formulate solutions, make estimates, or select among alternatives. However, available evidence provides no consistent basis for formulating universal, conditional rules for matching decision systems to different varieties of complex situations. In fact, it could be argued that where group or organizational members are dispersed, have unique personal information, yet must achieve a coordinated decision, judgments or choices are inevitably decentralized and the infrastructure required to centralize them is not only costly to establish and maintain, but is also too rigid and insensitive to important but obscure cues. In these circumstances reliance on a centralized hierarchy may even subordinate those at the top to the wishes, interpretations, or errors of those reporting to their superiors. For example, Captain Rogers was clearly the last person on the Vincennes who could have chosen not to launch missiles against Iran air. However, it can be reasonably argued that his choices were substantially preordained, subordinated to the incorrect judgment of his radar interpreter, junior officers' repetitions of incorrect interpretations of events, his personal objectives, and his mental set (Simon, 1945).

Perhaps in recognition of the reality that a leader's decision is inevitably collective in some substantive sense, there is little evidence about the conditions under which an individual leader's decisions are superior to alternative decision systems (such as requiring a majority vote to select among alternatives). Most experiments, inspired by trial jury deliberations and decisions, compare the behaviors and decisions reached under majority and unanimity rules imposed on the group, but do not explicitly consider leader decision making as an option. There is evidence in the "jury" experiments that decision rules affect decision processes, judgments or choices, post-decision opinions, and satisfaction. For example, during decision process there will probably be more conflict between members in groups using a majority rule than in groups using a unanimity rule (Falk, 1982). Groups using a majority rule are less likely to exhibit symptoms of groupthink than groups using unanimity (Kameda and Sugimori (1993). Less centralized rules like consensus tend to produce more accurate judgments than more centralized rules like reliance on a subset of members to make the decision (Holloman and Hendrick, 1972). Majority vote decisions are likely to be less extreme than unanimous decisions (Miller, 1985). Members of groups using the unanimity rule are likely to be more satisfied than those using the majority vote rule (Hart and Sung, 1976; Kaplan and Miller, 1987).

Only two experiments could be located which considered a leader's role in decision processes. In a business game the addition of a formal leader to student teams failed to change team performance (Remus and Edge, 1991). However, in a task requiring prediction of the order in which jurors in the film *12 Angry Men* would change their vote

form guilty to not guilty, groups relying on a leader were less accurate than groups using either consensus or majority vote decision rules (Holloman and Hendrick, 1972).

It should be noted that, although not every potentially relevant study has been summarized here, the total effort devoted to learning the implications of various decision rules is remarkably small. Nor were there any studies comparing alternative group decision rules for different types of decision tasks or situations. In all the studies the groups' task was simple, requiring only that different members' recollections or expectations be resolved in to a single response. Finally, none of the experiments comparing various group structures, decision systems, rules or schemes involved threat, time pressure or other sources of stress.

Effects of Stress

Concerns (c.f., Deitz and Thomas, 1991) about the impact of threats, stress, and anxiety on the judgments and performance of teams where high levels of reliability and competence are required are understandable. It is widely believed by researchers (e.g., Yates, 1990, 376) that, in general, increasing stress may improve decision making up to a point, after which it becomes dysfunctional in terms of its effects on individual and collective performance. However, a close reading of research on the effects of anxiety and stress indicates that this "inverted U" hypothesis can be misleading for many reasons.

One reason is that there is no evidence that any two of many kinds of stress have the same effects. For example, one might ask whether psychological (self-reported or perceived stress, Appley and Trumbull, 1967; Janis and Mann, 1977; Lazarus, 1966), task (e.g., stakes in possible decision outcomes - Yates, 1990), cognitive (e.g., information overload, Hamilton, 1982), occupational (e.g., role overload, Beehr, 1987), organizational (e.g., work pace - Quick and Quick, 1984), physiological (e.g., increased blood pressure or heat rate, Selye, 1956), ambient or environmental (e.g., noise or heat - Lazarus, 1966; Hamilton, 1979) and social (e.g., fear of peer rejection - Kaplan, 1983) stresses have the same effects on any given performance criterion (e.g., an individual's judgmental calibration or discrimination - Yates, 1990). In a similar vein, it seems likely that the stresses experienced prior to and during combat are unlike those experienced in most civilian task settings, so their effects on performance are not likely to be comparable (Driskell and Salas, 1991b).

A second reason for cautious acceptance of the "inverted U" hypothesis is that there is limited evidence that each type of stress will have unique effects. For example, Wright (1974) found that one stressor, time pressure, reduced attention was evident in greater emphasis on possible negative outcomes. But reduced attention due to another stressor, noise, was not systematically related to a particular attribute of the information environment. If this result generalized to other settings, environmental/ambient stress would be expected to result in a less biased sampling of incoming information than would increased time pressure. If so, providing general training for coping with stress would be less appropriate than developing specific coping behaviors for each type of

stress. For example, where threats can arise from many sources and time pressure is expected to be extreme, helping decision makers avoid excessive or even exclusive emphasis on negative attributes of the crisis would be essential.

A third reason for caution regarding the "inverted U" hypothesis is that, despite very many studies of the effects of various kinds of anxiety and stress (Appley and Trumbull, 1986), direct evidence regarding its impact on decision processes has important limitations. It is sparse and almost exclusively focused in individual rather than collective decision processes (Morgan and Bowers, 1995).

A fourth reason is that the evidence about the effects of anxiety and stress on decision processes is not only limited but inconclusive. After carefully reviewing 48 review and empirical articles focusing on individual judgment and decision making, articles published between 1980 and 1989, Mross and Hammond (1990) observed,

> "No generalization regarding the effects of stress on judgment and decision making can be readily justified on the basis of [these] articles.... It has not been clearly demonstrated that stress impairs, enhances, or has no effect on cognitive activity."

Several features of Mross and Hammond's review encourage even more caution for those concerned with group or other collective decisions. First, time pressure was the source of stress for nearly 25 percent of the articles; physical danger was a stressor in only four articles. Of the four, only one (Weltzman, et al., 1971) was an experiment indicating any adverse effects; a narrowing of focus. Second, they offered no conclusion about the effects of stress on group or organizational decision processes.

Furthermore:

> "The large literature regarding the effects of stress ... has nearly overlooked the effects on team processes and performance." (Morgan and Bowers, 1995)
> "Organizational ... research [has] been too little concerned with organizational and interpersonal factors that might serve as moderators, buffers, or even as antidotes to stresses and their effects.... [E]mpirical work in this promising area [organizational stress] is almost non-existent." (Kahn and Byosiere, 1990).

What guidance can the limited research offer those concerned with balancing efficiency and readiness? The following (tentative) propositions relating to stress were obtained from the Phase 1 macro analysis.

- Individuals who exhibit higher test anxiety review more information than those who whose test anxiety scores are lower. (Nichols-Hoppe and Beach, 1990). However, note Wright's (1974) findings regarding effects of time pressure listed below.
- High test anxiety individuals also review more previously considered, redundant information (Nichols-Hoppe and Beach, 1990).
- The greater the (test) anxiety, the less attention is focused on the task (Sarason, 1990; Wine, 1971).

Low anxiety persons take longer to make judgments than high anxiety people (Singh, Sharma, 1989).

Low anxiety individuals are less likely to conform than high anxiety individuals (Singh, Sharma, 1989).

The greater one's anxiety the more cautious the interpretation of events; i.e., the more stringent the criterion for reporting detection of a signal (in a signal detection task) (Geen, 1985).

Low test anxiety individuals perform selective attention tasks better than high anxiety individuals (Upadhayay, et al., 1985).

In selective attention tasks people experiencing physiological stress (due to random shocks) perform more poorly than those not under stress (Upadhayay, et al., 1985).

When exposed to the risk of being shocked, Type A individuals will exhibit more physiological stress - as measured by heart rate - than Type B individuals (Evans and Fearn, 1985).

Type A individuals will engage in more active monitoring of their environment when threatened (with being shocked) than Type B individuals (Evans and Fearn, 1985).

The greater the time pressure the fewer attributes of options are systematically used to make a choice (Wright, 1974). Note that this contrasts with the anxiety effects noted previously.

Also, the greater the time pressure the more attention focuses on negative attributes of the options (Ben-Zur and Breznitz, 1981; Wright, 1974).

Multi-Attribute-Utility decision models are less utilized under time pressure than without time pressure (Zakay and Wooler, 1984).

In decisions under certainty, the greater the time pressure the greater the reliance on non-compensatory heuristics (Zakay, 1985). Use of non-compensatory rules and confidence are positively related. Note that simulation results suggest this will not reduce the quality of decisions if the right heuristics (e.g., Elimination By Aspects, Equiprobability) are used, but not if other heuristics are invoked (Payne, et al, 1993, 143).

Also in decisions under certainty, the more time pressure the more teams will focus on the most important attributes of the situation (Edland, 1994).Training improves MAU decision model utilization only in absence of time pressure (Zakay and Wooler, 1984).

The greater the time pressure the less predictable the judgment or choice in a complex (curvilinear SJT) judgment task. That is, as time pressures rise, decision makers continue to use the same data and give each datum the same weight, but they use the data more erratically. In simple (linear) tasks time pressure has no effect on cognitive control (Rothstein, 1986).

The more time pressure a group or team experiences the less information it processes or exchanges (Goldstein, Reilly, 1985).

The extent of centralization in a team or group is unaffected by time pressure, contrary to the "threat-rigidity" literature (Goldstein, Reilly, 1985; Staw, et al., 1981).

There are no differences in efficiency between groups under high and low time pressure (Isenberg, 1981).

The distribution of "air time" among members will be more centralized in groups under time pressure than those not under pressure (Isenberg (1981). Thus, Communications become more centralized under time pressure.

The more perceived time pressure the lower the number of plans made using moderately complex planning schemes; but there are no quantity differences when the planning scheme is simple (Abualsamh, et al., 1990).

The more stress from environmental noise the less predictable the decision maker's evaluation of options (Wright, 1974). Thus both time pressure and environmental stress appear to cause decision makers to rely less consistently on their judgment models or heuristics.

Noise and task overload stress increase the use of the representativeness heuristic (Shaham et al., 1992).

Neither overload nor noise affect risk-aversion in evaluating options (Shaham et al., 1992).

When in noisy or crowded conditions, groups with predetermined structures perform more poorly than those without a previously specified structure (Worchel and Shackelord 1991).

Classification accuracy can be maintained over a wide range of work paces (Coury, Drury, 1986).

The more stress the greater the reliance on heuristics (Schaeffer, 1989).

The greater the stress the greater one's confidence (Schaeffer, 1989).

When judgments are made in the presence of others dominant or habitual attentional responses occur more than would be the case in the absence of others; the presence of others tends to reduce even more attention to factors a decision maker rarely notices when not under stress (Zajonc, 1965).

The greater the stress the more subordinates defer (refrain from questioning and hesitate to act in emergencies) to a superior's authority and interpretations of events (Foushee and Helmreich, 1988; Driskell and Salas, 1991a).

The greater the stress the more receptive group or team members (both high and low status) are to task information from others (Lanzeta, 1955; Torrance, 1967; Driskell and Salas, 1991a).

The more stress the greater the tendency to offer others solutions to problems before all decision alternatives have been considered (Keinan, Friedland, and Ben-Porath, 1987) (Keinan, 1987).

The more stress the less systematically alternatives are examined. (And the scanning patterns correlate with the quality of solutions to problems.) (Keinan, Friedland, and Ben-Porath, 1987; Keinan, 1987).

A group's decision quality is not affected by perceived time pressure or perceived threat (Turner, 1992).

Time pressure increases a group's decision making speed (Turner, 1992).

Threats cause arousal, and arousal is contagious, being spread by nonverbal cues in either face to face or distributed groups (Levy and Nail, 1993; Hatfield, et al., 1994). Thus, messages containing even a hint of worry or stress, particularly if

they are numerous and arrive at accelerating rates from many sources, may be expected to produce a vigorous sensation of panic or crisis.

External threats increase team or group cohesion (Sherif at al., 1961).

External threats provoke greater attention to, reliance on, and support for leaders' and influential members' behaviors and opinions, increase pressures to conform, encourage more consensus seeking (even if achieved by considering less information), and foster greater centralization, i.e., growing control of those with dominant perspectives over other members (Staw, et al., 1981).

Although not adequately documented, it has been argued, using social facilitation (Zjonc, 1965) reasoning, that performance will to depend on whether or not dominant responses encouraged by threat serve to improve decision making performance (Staw, et al., 1981).

It has also been argued, but not well documented, that:

- The effects of threat on the decision making unit depend on the source of threat. Internal threats reduce cohesion, encourage less respect for leaders and influential members, and induce decentralization or even conflict.
- External threats tend to cause the group or organization to become more mechanical in nature whereas internal threats may cause them to become more like organisms (Burns and Stalker, 1961).

These propostions, while not an absolutely exhaustive scan of all empirical findings relevant to the effects of stressful conditions on decision processes,[53] are noteworthy in several respects. Most are founded on a single study using decision tasks which differ from other studies' tasks in undefined ways. Replications demonstrating that findings from ad-hoc groups of college students in simple task settings are needed to establish the propositions' generality. Another observation is that only a very few of all possible sources of stress have been examined. Yet another is that these results provide virtually no evidence about the joint effects of two or more stressors which are experienced simultaneously. It seems reasonable to speculate that the cumulative effects of multiple stressors is not additive, but multiplicative; each additional source of stress accelerates the arrival and magnitude of dysfunctional decision making practices. Overall, studies of the effects of various sources and forms of stress on decision making reinforce the reservations expressed by Mross and Hammond (1990) and Morgan and Bowers (1995) noted earlier.

There a many propositions which appear to have received no empirical attention but which have potentially important implications. For example

Units achieving very high levels of efficiency on routine activities develop dominant habits which hinder decision making in crises.

Organizations, groups or teams which have not faced crises and those which have coped successfully with one source or type of crisis may make equally good decisions.

Training teams for coping for crises will be effective to the extent that:

[53] Franken and O'Neil (1994) is one study which was not available to us. It examined the effects of anxiety in Navy teams on their performance.

Many different kinds of crises are imagined when developing training scenarios, and

Patterns of information associated with each type of crisis can be distinguished by members of training groups (Klein, 1993), and

Members are able to generate new interpretations of information patterns when initial interpretations are unproductive (Gettys and Fisher, 1979; Gettys et al., 1987).

This review of some of the research which is most relevant to this project should have reinforced the concerns noted in Phase 1. Most propositions have not been replicated and have been tested in contexts that are both unique and far less complex than those decision makers face every day. The next section describes how ALCO was used in an attempt to resolve some of the limitations of the literature which is relevant to this project.

Piloting ALCO

ALCO experiments were conducted in relatively uncharted waters. Given the limited resources available for creating personal and team incentives, great effort was made to assure that experiments would produce useful insights. Thus, prior to attempting a complete experiment, a series of pilot partial experiments with ALCO were conducted over a period of nearly two years.[54] They addressed not only the ALCO challenges discussed earlier, but also those difficulties involved in any experiment requiring multiple subjects per observation, unknown strength of effects of manipulations of independent variables, and similar problems. This involved too many obstacles and false starts to fully describe in this report. Only the most difficult are noted here.

During piloting it was discovered that student subjects, even graduate students, required at least 90 minutes of training and another 60 to 120 minutes (depending on the complexity of the simulation situation) to become proficient. Although most subjects became very involved, even in designs without financial incentives, feedback indicated the initial learning curve was steep and frequently frustrating.[55] It was discovered that subjects became much more patient and became less frustrated when they were informed at the outset that their experience would be much like flight simulation, and they could only expect to fly effectively if well trained.

Early debugging and piloting involved undergraduates because they are routinely available in a subject pool. This proved unworkable. The time commitments required of them in ALCO studies were longer than their other options for satisfying the pool requirement. Those who did sign up to participate often did so to assure they would have access to some study satisfying the requirement. When other options arose and

[54] These constituted partial experiments at best. Each examined a different design question.

[55] Frustrations for researchers and subjects were greatest when the system collapsed. This was a frequent problem when the computer laboratory was moved and new hardware and network software was installed, necessitating substantial revisions in the ALCO software.

were exercised they failed to appear at the appointed times[56]. Of those who did participate as scheduled, not all were willing to exert the effort required to become proficient. These, and other problems thwarted the first efforts to debug our research design. It was concluded that only subjects who volunteered would be suitable for projections of this kind. Further, it was determined that only MBA students would be sought as they are more mature and have more work experience.

One pilot study demonstrated that MBA participants substantially increased their attentiveness to the ALCO situations they confronted when individual and team compensation incentives were supplemented with competition and public feedback about all teams' performance. As a result, as described later, the major study mounted in Phase 3 used a tournament pay system coupled with public posting of results. The issues and procedures in that experiment are described in the following sections.

This kind of study has been criticized by those who emphasis naturalistic decision research for many reasons (e.g., Klein, 1993). Objections to the use of student subjects who are placed in ad hoc teams and given too little time to formulated social systems are common. However, there are reasons to believe that many laboratory studies do generalize to field settings (c.f., Locke, 1986; Levin, et al., 1983; Driskell and Salas, 1992). Given that field experiments are even more difficult to conduct than laboratory studies, it is a wiser use of resources to begin with laboratory experiments of kind reported here.

Design

The most extensive experiment used 39 experienced MBAs randomly assigned to 13 three person teams[57] in a 2 x 2 within-team design (Table 2). The four conditions were designed to examine the effects of different levels of crisis severity and two decision making rules or systems. In the "local," low severity, condition only one member's advisor unexpectedly (and without warning) became far less accurate than previously. In the "global," high severity, case all members' advisors became less accurate at the same time, again without warning. In the "dictator" or leader decision system one member's estimate of the environmental parameter's (**E**'s) value constituted the team's response (**T**). When it was submitted by the leader the trial ended and a new one began. In the consensus, unanimity, decision system every member had to agree on the same value of the environmental parameter's estimate (**T**) to conclude a trial. Major dependent variables included individual and organizational performance, communications, commitment (cohesion), and stress.

Two sessions were conducted for all participants. The first trained them in ALCO and collected personal data. They learned, for example, how to: open channels of

[56] It was later discovered that the prevailing norm was that signing up to participate in a study did not constitute a binding promise to appear. This was even true in many instances when phone call reminders had been received within the previous 24 hours.
[57] Groups, teams, and organizations differ on many dimensions (Swezey and Salas, 1992). The results of this experiment cannot be generalized to organizational settings.

communication, send, receive, and review messages, acquire advice from their sources, transfer resources to other members, review others' past activities, and interpret personal and team feedback. The second, "baseline" session, provided an opportunity to become proficient in the use of those skills and explore what could be achieved when the skills were used effectively. Thus, by the time participants encountered the first experimental session they had achieved reasonable proficiency in operating the system.

As indicated in Table 2, data were collected in four experimental sessions each containing three trial blocks. The first and third trial blocks within each session were non-crisis situations involving five and four trials or periods respectively. However, in the second block either one (local - low severity) or all (global or high severity) members' advisors become less useful for six trials. (This change was unannounced, but subjects learned to anticipate it after a few sessions.) Thus, teams had opportunities to develop high levels of efficiency in routine operations before confronting challenging conditions which required a "shift of cognitive gears" (Louis and Sutton, 1991), innovation in individual task performance, and changes in the team's patterns of interaction to respond well to the crises.

Table 2
Experimental Design

Order				Order				Order				Order			
DecRule	Crisis	Periods	Hrs	DecRule	Crisis	Periods	Hrs	DecRule	Crisis	Periods	Hrs	DecRule	Crisis	Periods	Hrs
TRAINING SESSION:															
Majority	None	10	3	Majority	None	10	3	Majority	None	10	3	Majority	None	10	3
BASE-LINE SESSION:															
Majority	None	10	3	Majority	None	10	3	Majority	None	10	3	Majority		10	3
SESSION 1:			3				3				3				3
Dictator	None	1 - 5		Consensus	None	1 - 5		Dictator	None	1 - 5		Consensus	None	1 - 5	
Dictator	Global	6 - 12		Consensus	Global	6 - 12		Dictator	Local	6 - 12		Consensus	Local	6 - 12	
Dictator	None	13 -16		Consensus	None	13 -16		Dictator	None	13 -16		Consensus	None	13 -16	
SESSION 2:			3				3				3				3
Consensus	None	1 - 5		Dictator	None	1 - 5		Consensus	None	1 - 5		Dictator	None	1 - 5	
Consensus	Global	6 - 12		Dictator	Global	6 - 12		Consensus	Local	6 - 12		Dictator	Local	6 - 12	
Consensus	None	13 -16		Dictator	None	13 -16		Consensus	None	13 -16		Dictator	None	13 -16	
SESSION 3:			3				3				3				3
Dictator	None	1 - 5		Consensus	None	1 - 5		Dictator	None	1 - 5		Consensus	None	1 - 5	
Dictator	Local	6 - 12		Consensus	Local	6 - 12		Dictator	Global	6 - 12		Consensus	Global	6 - 12	
Dictator	None	13 -16		Consensus	None	1 3-16		Dictator	None	13 -16		Consensus	None	13 -16	
SESSION 4:			3				3				3				3
Consensus	None	1 - 5		Dictator	None	1 - 5		Consensus	None	1 - 5		Dictator	None	1 - 5	
Consensus	Local	6 - 12		Dictator	Local	6 - 12		Consensus	Global	6 - 12		Dictator	Global	6 - 12	
Consensus	None	13 -16		Dictator	None	13 -16		Consensus	None	13 -16		Dictator	None	13 -16	

Each team experienced all four experimental conditions in one of the four orders indicated in Table 2, permitting an examination of learning or inhibition. That is, it was anticipated that the habits acquired in coping with one experimental condition might carry over in to another, particularly during the first (non-crisis) trial block of the new condition (Gersick and Hackman, 1990). In the first experimental session teams encountered their first crisis during the second trial block. It was anticipated that teams facing high severity crises would notice them and "shift cognitive gears" before teams facing low severity crises. As Gersick and Hackman (1990) noted, groups faced with severe challenges are more likely to notice the change and abandon existing habits than are those faced with lessor challenges. They also argued that as challenges become more frequent, particularly when the challenges are very serious, members become less and less likely to rely on habitual patterns of behavior.

Teams were offered substantial incentives to make good personal and collective decisions as a means of achieving good performance. The criterion for individual performance on each trial was the accuracy of the subject's estimate of their own (e.g., **A** in Figure 1) unique parameter's current value. The criterion for collective judgment was the team's accuracy in estimating **E**, the difference between **T** and **E**.

In each experimental session each member of the team with the best performance received \$20 for that session. Members of the second best team received \$10, and those in the third best team received \$5.[58] Members of all other teams received nothing for that session. To encourage high effort throughout the experimental sessions all participants were also eligible for overall payments. The best three teams in the experimental sessions received \$50 for each member, each member of the next best three teams received \$20, and \$20 was paid to members of the next three best teams. Thus, compensation for participation could range from nothing to \$130.

Data about the individual characteristics of each team member were collected during the training session for two reasons. The first reason was to achieve greater statistical control through procedures such as the use of covariates. The second was to attempt to clarify mixed results from earlier studies. It is unclear whether the composition of the team, for example, as defined in terms of personality profiles, will affect decision processes and performance. After reviewing experimental studies of group performance, Hare (1994) argued that the mix of personalities in a team, together with their skills, experience, and morale (among other factors) will affect problem solving and, more generally, group productivity. One study found that groups designed to be heterogeneous in terms of the need for dominance were more effective in organizing communications and performing their task efficiently (Lampkin, 1972). Other research found that groups with heterogeneous personality profiles solved problems better than homogenous groups (Hoffman and Maier, 1961), and members were more likely to

[58] To further enhance participants' motivation to perform well, two parallel tournaments were actually conducted, one each at the University of Iowa and Notre Dame. Thus, for each experimental session a total of six (of the 13) teams' members received some compensation.

challenge one another's incorrect behavior (Goldman, et al., 1968). (If true in the complex task setting of this experiment, homogeneous groups would be outperformed by heterogeneous groups.)

However, there is some evidence that homogenous groups communicate more effectively, cooperate better, and experience less internal conflict (Bass, 1982; Lodahl and Porter, 1961; Bass, 1965; Hoffman, 1959).). Meta-analysis reveals that cooperative orientations produce better group performance, particularly where tasks require exchanges of information (Johnson, et al., 1981). If a crisis should cause some to become more competitively oriented, attempting to dominate collective processes and outcomes, the resulting conflicts could hinder performance. On the other hand, if members have and retain cooperative orientations, constructive controversy among members should help achieve high performance (Tjosvold, 1995, page 90 ff.).[59]

Overall, it remains unclear whether or not personality matches among members will make a difference (Driskell et al., 1987). "[T]he dominant theme in the empirical literature is ... much speculation but little convergence." (Driskell, et al., 1989).

Research in other contexts, where group or team composition is not an issue, may be relevant to the effects of personality on team decision making. Recent evidence has shown that five dimensions (the "big five" - extroversion, agreeableness, conscientiousness, emotional stability, and openness to experience) reliably capture individual differences (Digman, 1991). Furthermore, the big five, particularly conscientiousness, are related to individual task performance in work settings (Barrick and Mount, 1991). A few individual studies, summarized in Driskell, et al, (1989) suggest that these dimensions, particularly stability and extroversion, may also predict team performance. However, in complex, multi-task settings like ALCO, not all personality traits will be equally relevant to all decision making activities and performance (Driskell, et al, 1989). Thus, we were encouraged to use the Personality Characteristics Inventory (PCI), an instrument which has demonstrated substantial reliability and validity (Barrick and Mount, 1993), to explore how the mix of personality characteristics in each team might relate to the teams' patterns of activities as well as its performance.

Due to the cognitive aspects of the task situation it was expected that individual cognitive characteristics could also be important compositional considerations. Therefore the short form of the NFC, Need for Cognition questionnaire (Cacioppo et al., 1984) was also answered by each participant at the end of the training session. The short form has demonstrated reliability comparable to the original (long) form (Cacioppo and Petty, 1984) and has exhibited substantial validity (e.g., Tolentino, et al., 1990; Sadowski, 1993) and provides measures which are unaffected by gender (at least for

[59] Constructive controversy requires members to express all their thoughts and emotions, seek to understand others' thoughts and emotions, perceive that everyone will share the same fate, attempt to influence others and be subject to being influenced, exhibit respect for other members, and seek solutions that are mutually satisfying.

college students; Sadowski, 1993). NFC assesses an individual's motivation to engage in thinking and cognitive endeavors. The NFC is also useful because persuasion is a key part of collective decision processes, and there is clear evidence that the need for cognition affects persuasion processes and their outcomes (Cacioppo et al., 1983). In terms of specific aspects of the decision process, it was reported that time pressure affected low NFC participants' search patterns, but not those of high NFC participants' search (Verplanken, 1993). Under time pressure participants used search strategies that were more variable in amount of information assessed across alternatives, indicating the use of more heuristic strategies, than when not under time pressure. Data suggest that where team members have low needs for cognition they will probably experience more anxiety about communicating with others (Wycoff, 1992). There is some evidence that NFC is related to scores on the MBTI (Claxton and McIntyre, 1994). The NFC has the added advantage of correlating with measures of general mental ability (Cacioppo and Petty, 1982) like the ACT and grade point average (Waters and Zakrajsek, 1990). Mental ability is the best single predictor of task performance (Schmidt at al., 1992). For all these reasons, it seemed likely that the higher the teams' average NFC score, the better it would be likely to perform.

To explore the effects of other composition variables a demographic questionnaire was also administered to all participants at the end of training. It collected work-related data on years of part-time work, full time work, supervisory and managerial experience, and self-assessments of important job skills (for example, planning others' work, decision making, designing work systems, working as a team member, e-mail). It also obtained data on participants' ethnic background, native language, age, sex, and undergraduate major. Finally, it obtained proxy measures for intelligence: grade point average, and scores on college admission examinations. Intelligence has been moderately correlated with team performance in pervious research (Driskell, et al., 1989).

Results

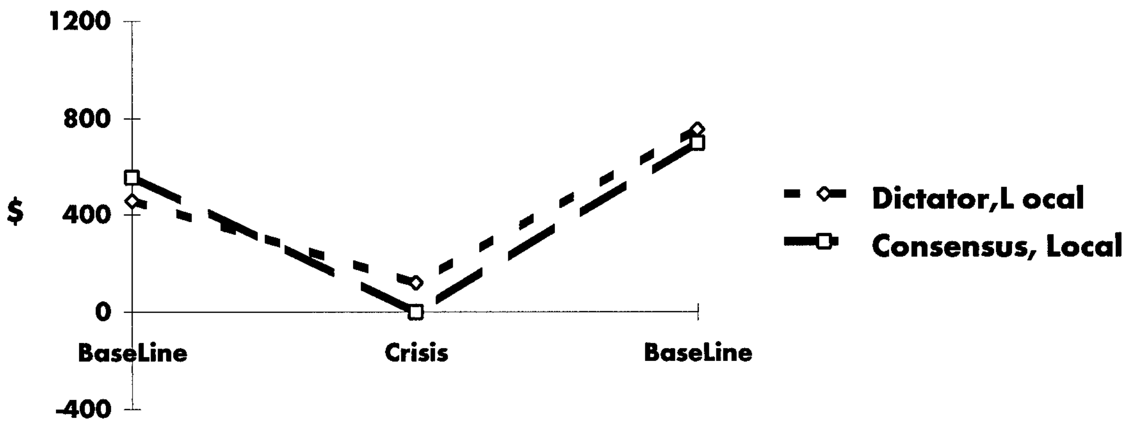
Distributions of personal data, such as need for cognition scores, did not vary by experimental condition.[60] Due to the small number of observations in each experimental condition and the contamination of effects due to decision rule and type of crisis by the four experimental orders, all of the other results obtained in this experiment must be treated with caution. Furthermore, all confidence intervals[61] for effect sizes contained zero, indicating the need to collect more data before drawing firm conclusions. The following graphic displays capture the most noteworthy performance and communication differences which were obtained. The commentary preceding each figure indicates very tentative conclusions.

[60] In retrospect, this is not surprising. College students are a reasonably homogeneous population.
[61] Significance tests were avoided for reasons discussed in Schmidt, 1996.

Crisis manipulations were effective. Although teams in all conditions performed equally well prior to crises, crises had the expected effects of reducing team performance.

Figure 2

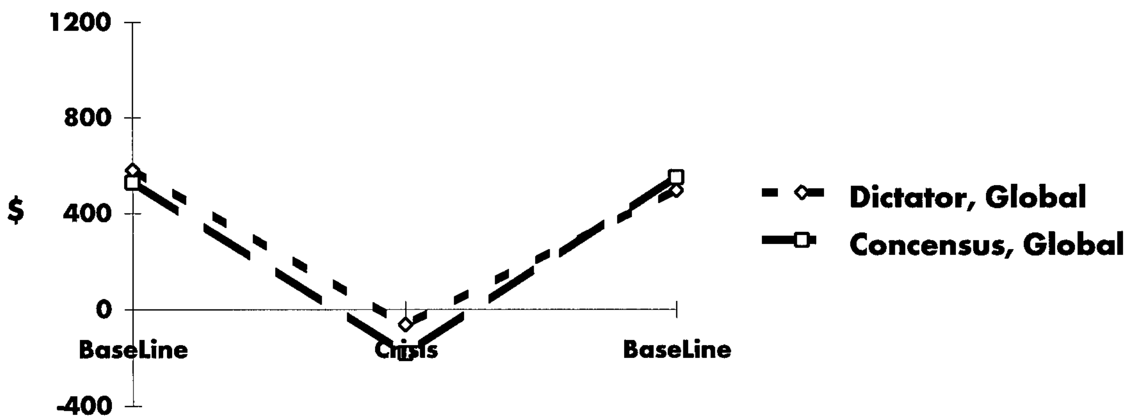
Mean Performance in Sessions 1 and 2



Fig

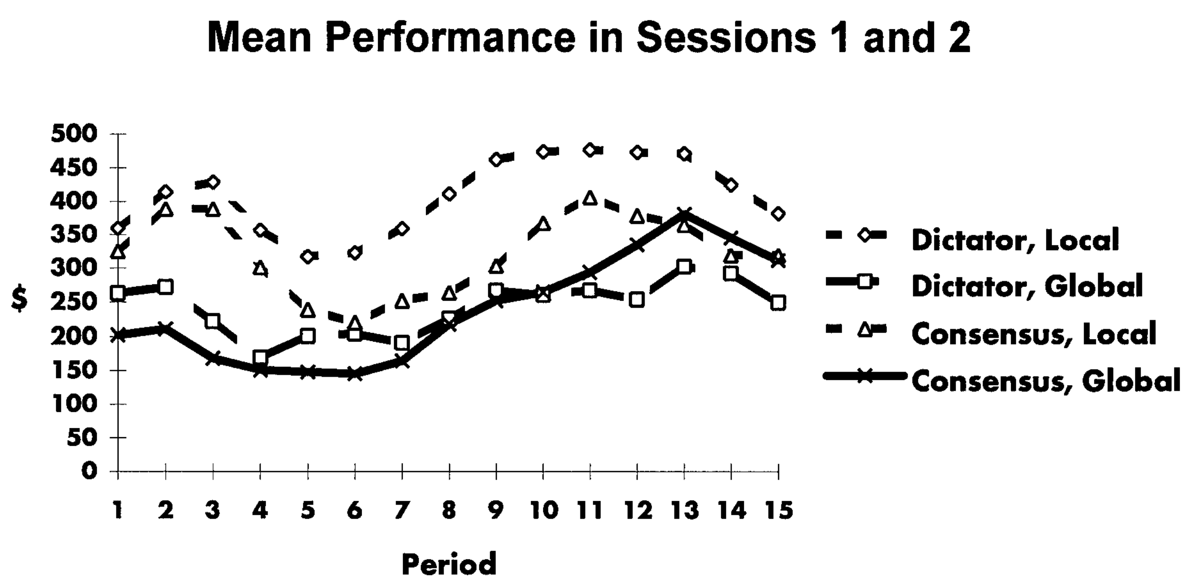
Figure 3

Mean Performance in Sessions 1 and 2



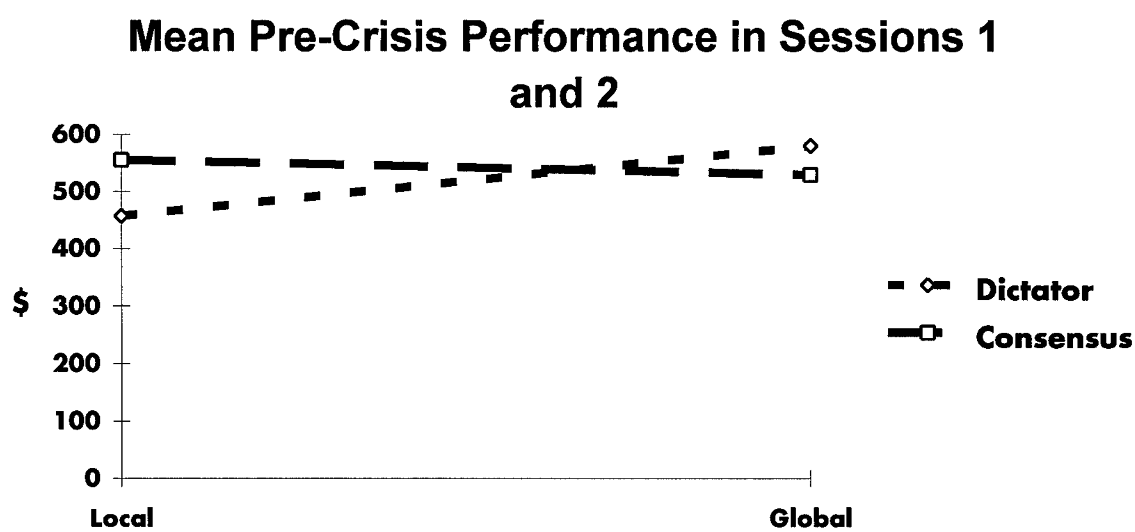
Performance tended to be better when crises were less severe, despite the fact that they were more difficult to notice. Decision systems had less impact. For example:

Figure 4



The patterns in the following three figures are provocative. The first indicates that performance for all teams was typically comparable prior to crisis.

Figure 5

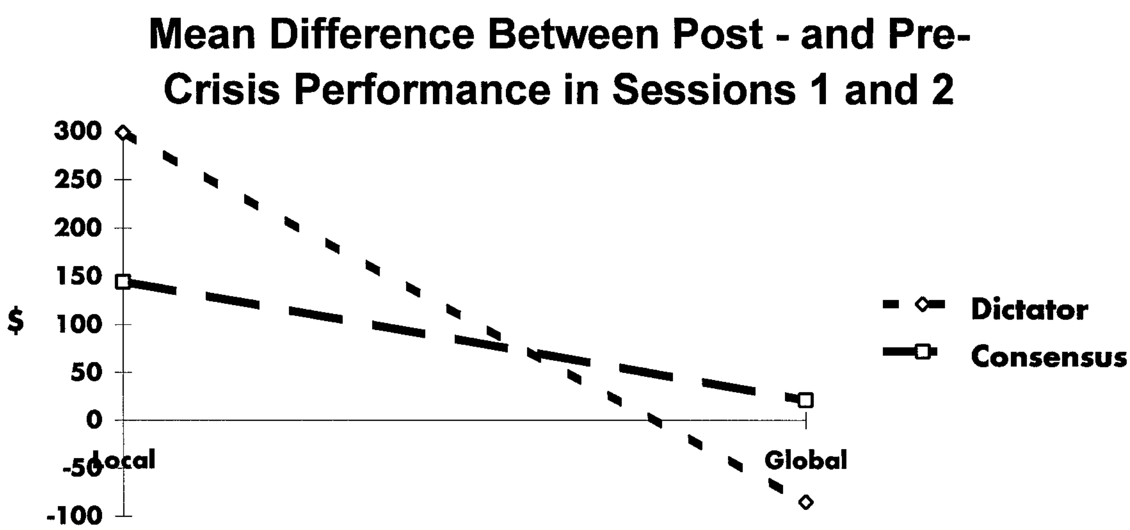


And performance returned to pre-crisis levels after global crises, but exceeded pre-crisis levels following local crises This suggests only global crises spill over into later non-crisis activities.

Figure 6

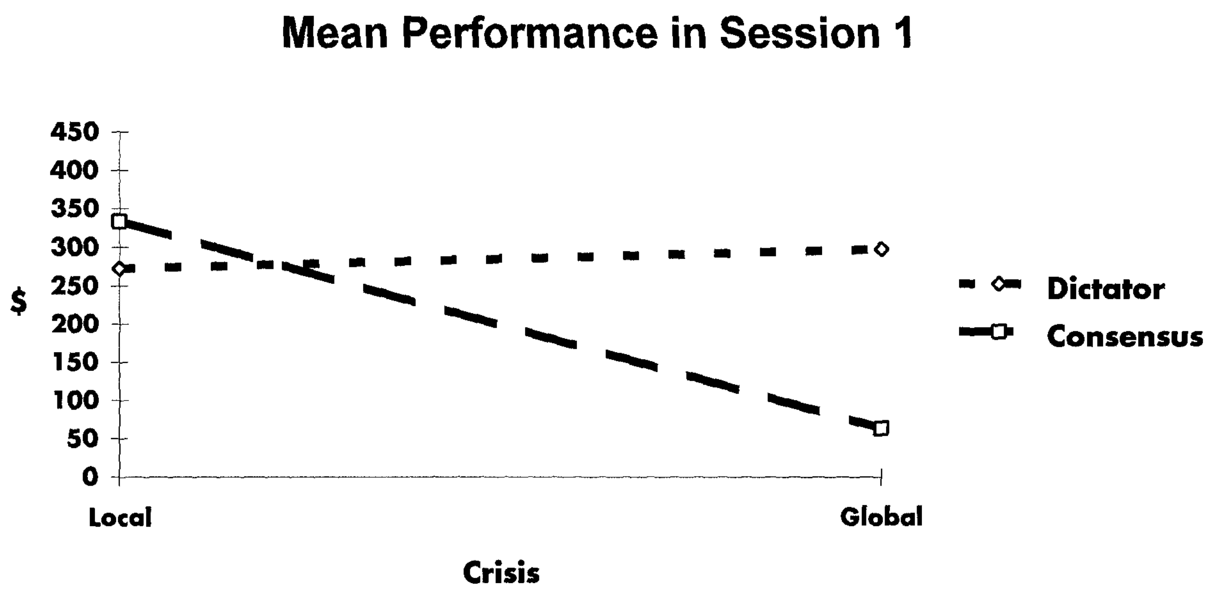
Differences between pre- and post-crisis performance depended on both type of crisis and decision rule. Dictatorship was most useful when crises are local, and was more dysfunctional when crises are more extensive.

Figure 7



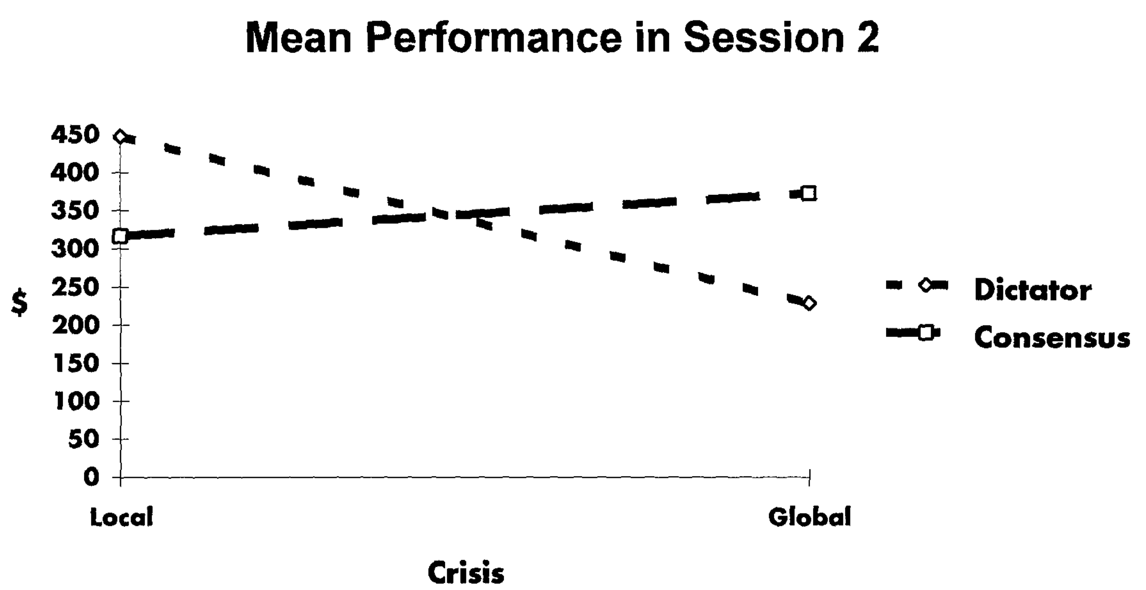
Effects of decision rule and type of crisis appear to depend on previous experience. For example, compare the results for the first two experimental sessions. In session 1 teams had no previous experience with crises of any kind and they fared best under dictatorship when facing the most severe crisis.

Figure 8



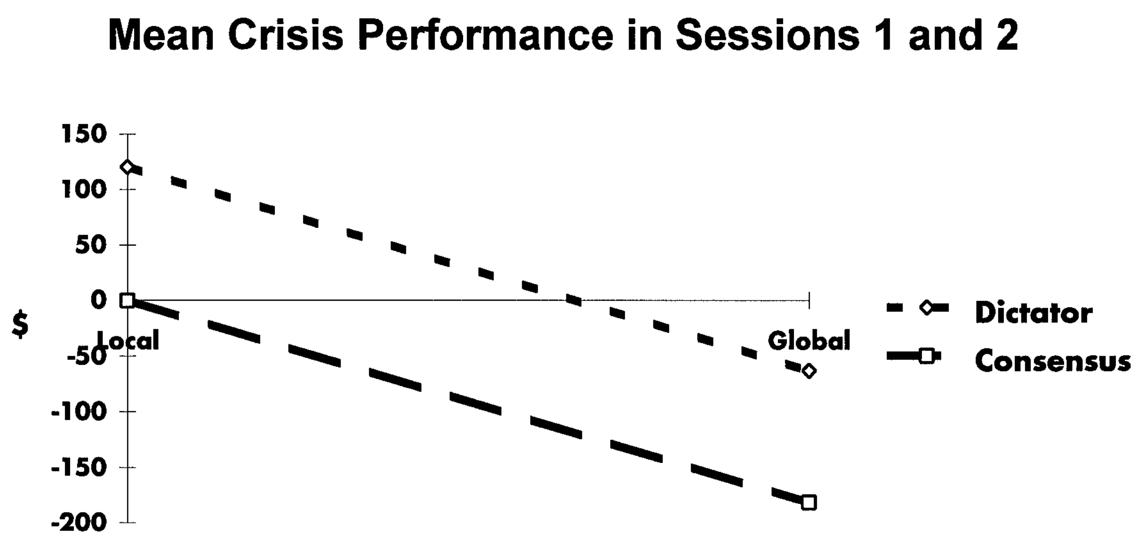
After having gained some experience, team performance depended on an interaction between decision system and severity of crisis. Compared to the consensual system, dictatorship was less useful in severe crises than in local crises.

Figure 9



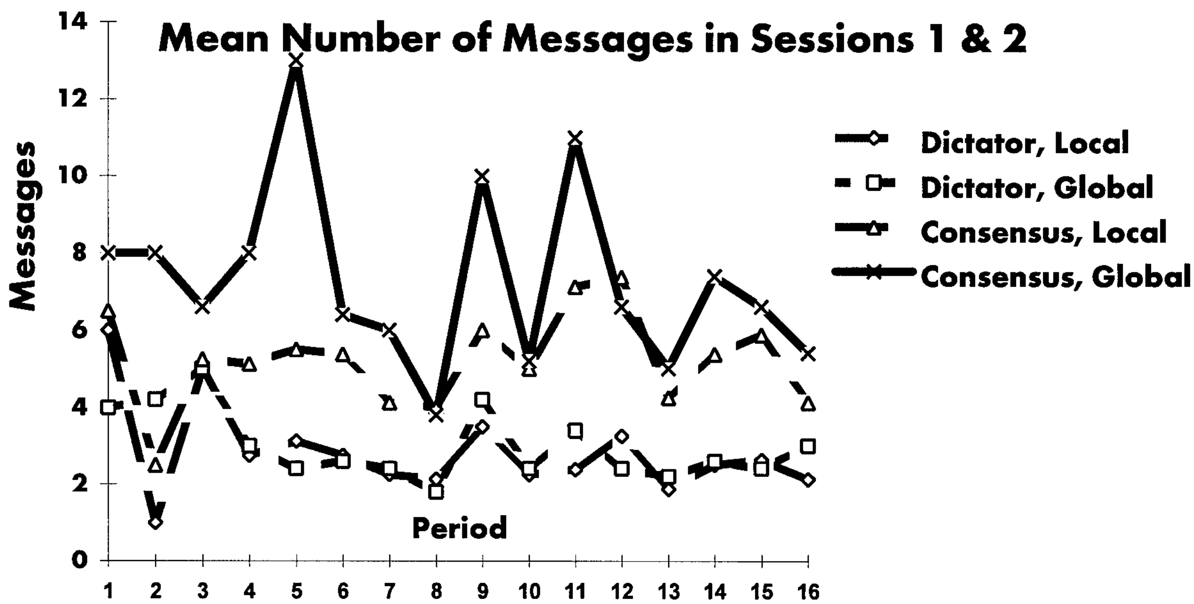
During crises dictatorships outperformed consensus teams and severe crises caused lower performance than local crises.

Figure 10



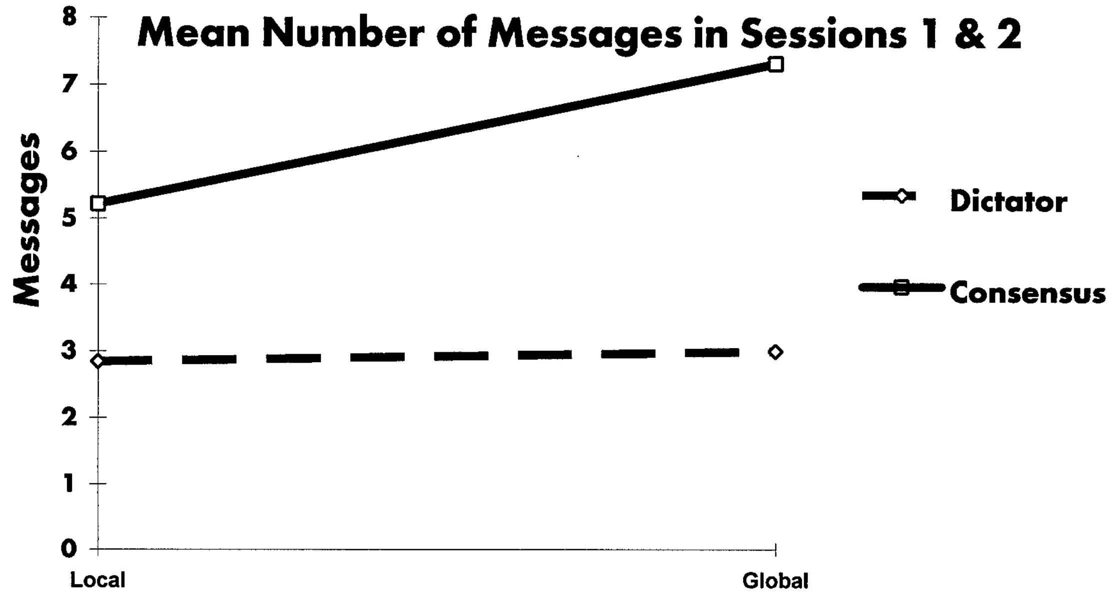
When crises affected all members, more messages flowed when all members were compelled to agree on the team's response than in other conditions.

Figure 11



As anticipated, teams required to reach consensus communicated more extensively, particularly when facing severe crises.

Figure 12



By the time teams had completed training and practice sessions, their communications during experimental sessions was very task oriented and, as seen in the next three graphs, there were no noticeable differences in content between crisis and non-crises periods.

Figure 13

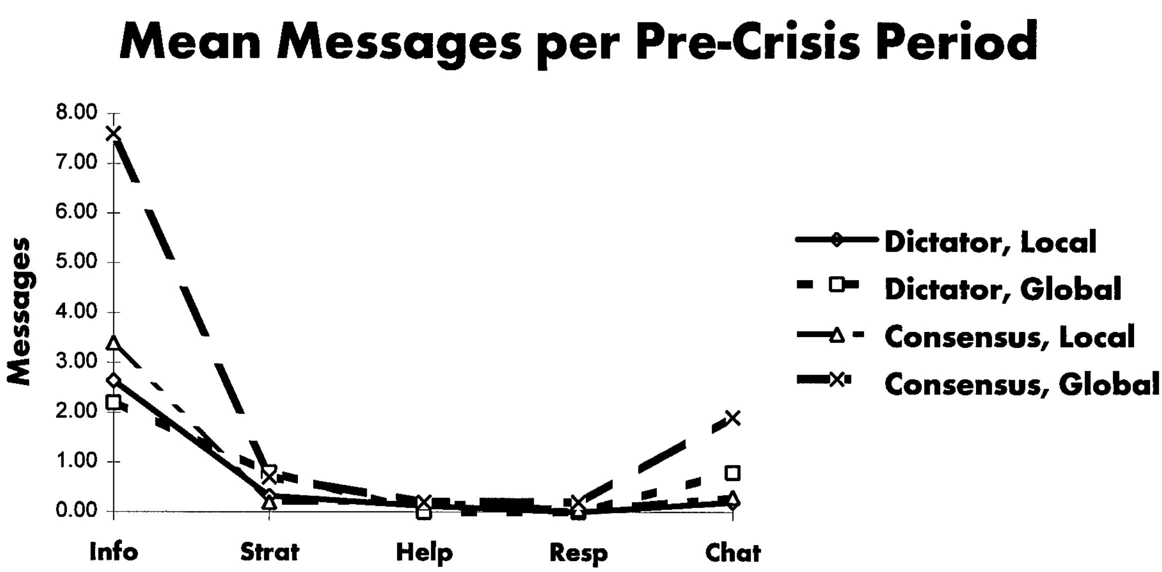


Figure 14

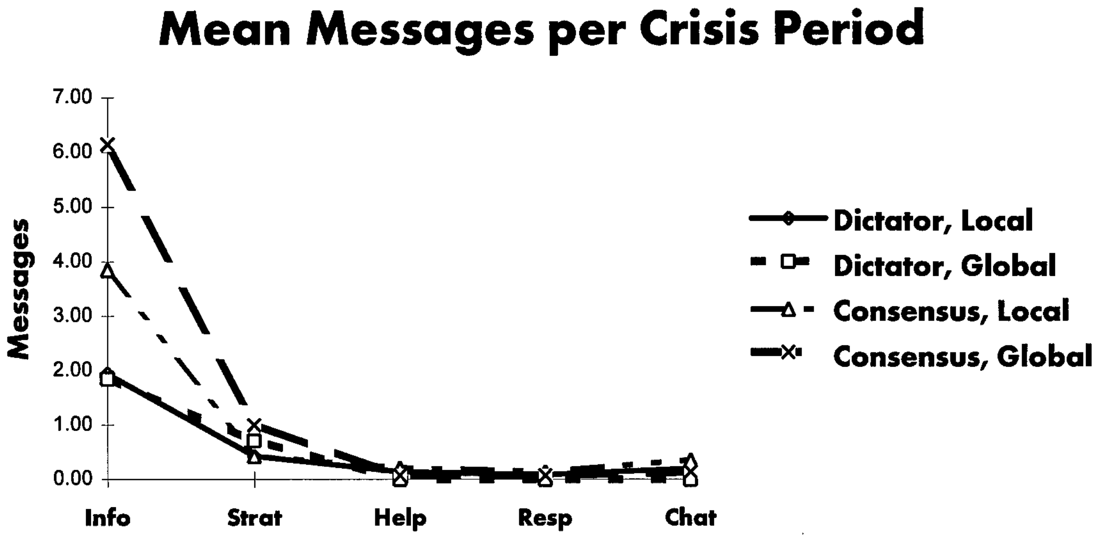
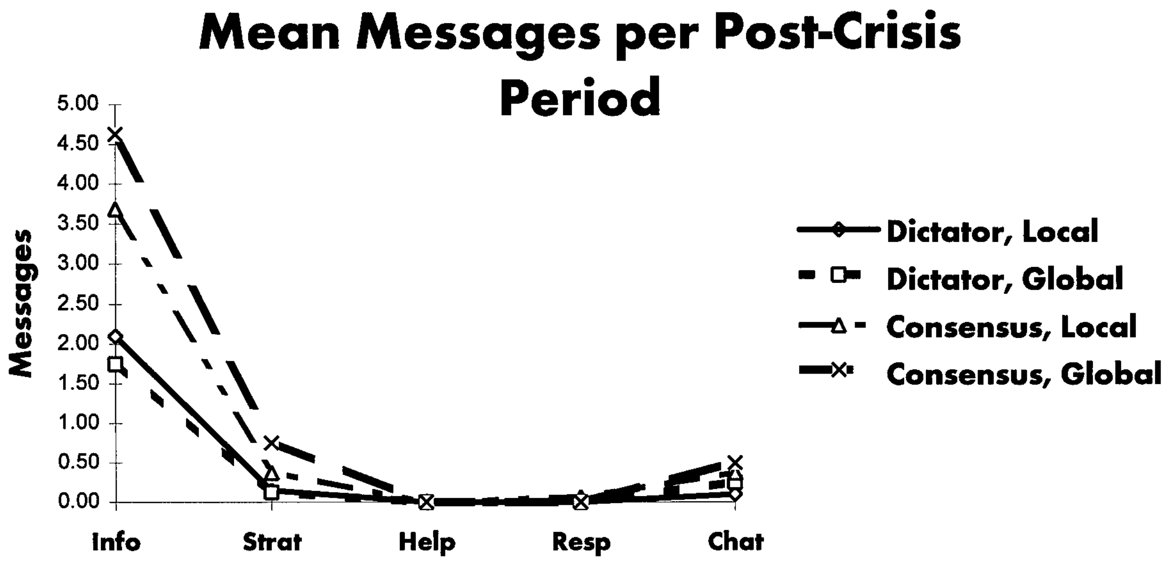
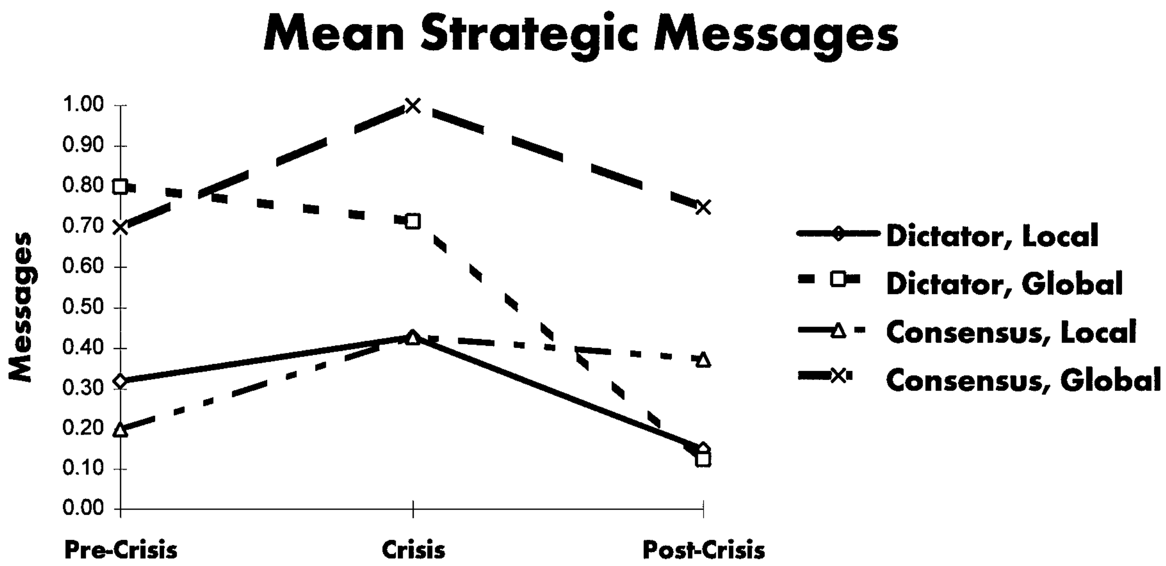


Figure 15



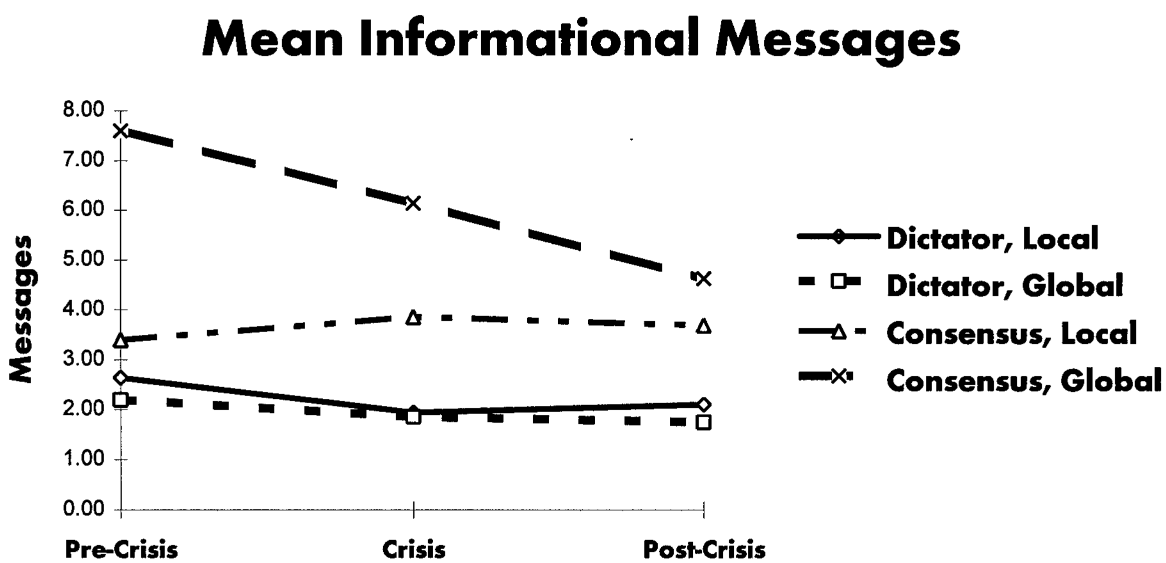
Suggestions for altering ALCO processes and structures were more common during crises, but crisis type and decision rule interacted in a complex fashion.

Figure 16



In most conditions the number of messages which provided other team members basic information was quite stable.

Figure 17



Discussion of Experimental Results

As noted earlier, these data require replication before the tentative observations which have been offered can be accepted. However, the following points seem likely to be confirmed.

- Highly motivated, bright people find it difficult to focus on the non-obvious methods for improving performance. There were several indicators. Strategic suggestions were far less common than informational messages. None of the members sought to achieve better performance, even during crises, but attempting to review their peers' past activities. Also, the density of flows of messages in channels was essentially the same whether or not there was a crisis.
- Implicit, but central, tasks are less likely to affect behavior than those explicitly assigned. For example, there was only minimal examination of past performance reports which was required to model co-variation between accuaracy and payback.
- Members can adapt to changes in each person's relative importance to team performance. Subjects did learn to allocate resources in proportion to impact of each member's individual performance on team accuracy.
- Failures (e.g., in communications systems) are detected, but not always quickly. One reason is that teams tended not to institutionalize lessons from past experience. For example, teams did not assign responsibility for monitoring key variables to specific individuals once the impact of those variables on performance was evident from experience.
- The value of different decision systems varies depending on the teams' experience and the type of crisis the team currently faces. However, the interaction patterns do not conform to any known theory and are not readily interpretable.

Recall the earlier argument that personal, group, and organizational success (sometimes even survival) require finding an appropriate balance between efficiency and readiness. In this context, the experimental results suggest that participants failed. For the most part they focused more on routine tasks, satisfying themselves with only modest adjustments in their system when crises arose. Even though it was not easy to perform even the routine activities with great efficiency, adapting organizational procedures to crises was even more problematic.

It is most likely that participants in this experiment found it difficult to recognize and exploit the most efficient ways to modify their system and procedures to cope with crises. This despite: 1) being selected because they were graduate students in business averaging more than two years of full time (typically non-managerial) work experience, 2) having been trained in the system's properties, and 3) having been warned to concentrate as much on system management and innovation as on more obvious individual and team task demands. In fact, once they made discoveries about the kinds of crises they faced they appeared to be content to make only simple adjustments. Aggressive efforts to discover and use additional, more complex coping tactics or strategies were uncommon. These behavioral patterns are consistent with

Gersick and Hackman's (1990) speculations that people are highly attracted to routines, finding them easy to adopt and difficult to abandon. As Hackman and Morris (1975) also observed, teams exhibited few signs of strategic thinking; planning for coping with new conditions in different ways that were used in routine conditions was rare.

Gersick and Hackman speculated that teams may find so much comfort in existing routines, and so many risks or costs in attempting to make adjustments, that they unconsciously increase the intensity of those dominant habits when aroused by a crisis, consistent with other manifestations of social facilitation (Zjonc, 1965) in individual behavior. This would also be predicted by the Icarus paradox exhibited by several leading firms (Miller, 1990).

More aggressive response efforts had been expected for two major reasons. First, the crisis conditions had been pre-tested and usually caused team performance to plummet. Thus, members could hardly fail to notice the situation and think about the need to find new ways to respond (Weiss and Ilgen, 1985). Second, aggressive responses were expected because participants were highly motivated, not only by the large potential earnings available in the tournament, but by their concern for demonstrating their administrative abilities were at least equal to their peers'.

These results, like those of Hackman and Morris (1975), and the organizational inertia reported by Miller and Friesen (1984), do not provide many causes for optimism. It appears that imaginative and aggressive exploration of new or additional system designs for coping with crises more quickly or at less cost will not be observed in the absence of quite large incentives. Can it be possible that it is necessary to experience the real possibility of personal bankruptcy, death, or similar extreme threats before initiating intense search for new responses?

Informal discussions of these experimental results with experienced managers and senior executives reveal that, despite (perhaps due to) their own experience, they have the same tendencies. When they do think in terms of altering their systems in response to threats, their actions appear to demonstrate reliance on the availability heuristic (Tversky and Kahneman, 1972). That is, they "benchmark" (imitate) what they consider to be the best practices of other organizations. For example, in the past decade firms typically responded to large increases in competitive pressure by cost reduction strategies like downsizing rather than revenue enhancing strategies.

If administrative experience is unlikely to induce more numerous or more sophisticated approaches to forestalling crises before they occur or coping with crises when the arise, graduate education in management may not be a satisfactory alternative. Participants in the experiment were drawn from two of the leading MBA programs in the United States. However, neither program emphasizes crisis management or the case method. Given that senior administrators confess to not anticipating crises or responding in complex fashion to crises, one must wonder how much could be accomplished by participants whose graduate training had focused on cases involving crises. Certainly all forms of training, including executive short courses on leadership, reengineering

processes, and communications and negotiation skills, lack the visceral impact of being a member of a team or organization facing extreme threat.

Use of ALCO has implications for those who would conduct similar experiments. Most researchers are likely to exhibit overconfidence with respect to several necessary activities. An appropriate simulator must be built and debugged. Designs must be very carefully thought out and efficient. (Even within-team designs like the one reported here only achieve a threshold of efficiency.) Longitudinal effects are likely in real organizations, but are difficult to include in experimental simulators. The ease with which viable combinations of simulator parameters can be established for an experiment will be overestimated. Mature and experienced people must be persuaded to commit substantial time as subjects for relatively modest personal returns. Researchers must find enough of them who can meet at one time to achieve reasonably robust results (something not achieved in Phase 3). Researchers will underestimate the time it will take subjects to learn to use the system effectively. Funding agencies should beware of proposals which are overly optimistic in these and similar respects.

There is a motivational advantage to using simulators like ALCO for experiments. Most participants become very involved. This is beneficial for recruiting subjects and eliciting their peak performance over long experimental sessions. Unfortunately, software development must constantly accelerate. For example, today's subjects prefer icon driven systems. (Unfortunately from this perspective, ALCO is a DOS, menu driven system). Adaptation and even reprogramming, of existing simulators like SIMNET (Alluisi, 1991; Miller and Thorpe, 1995) may be required.

Conclusions from Phases 1 - 3

Had the project found solutions to the ICARUS language's problems, it would have significantly enlarged the range of situations to which discrete event simulation can be applied. Incorporation of expert systems into simulation models could have an impact not only on organizational simulations and crisis modeling, but on conventional logistical and financial simulations. Simulation efforts like Carley's (1986, 1991, 1992; Carley and Prietula, 1994) shoud be encouraged because, even though they don't have the flexibility ICARUS would provide, they do include variables from the individual through organizational environment levels. However, their value will be limited as long as they continue to not be validated with experimental studies.

It has been nearly 10 years since Freeberg and Rock (1987), following their attempt to derive a taxonomy of team performance based on meta-analysis of 117 studies, stated, "[T]here have been glaring deficiencies in the team performance literature." Among those they emphasize are "methodological quality control" (particularly among studies which are published in technical reports but not peer-reviewed journals), especially better study designs. This project demonstrates that their ideas about good design should be extended. Specifically, designs are needed placing far more emphasis on those variables affecting decision processes which are inherent in the fabric of

organizational activities. Those designs should include factors at the individual level and at the group, organizational, and organizational environment levels as well. Without extended designs incorporating all these levels it is impossible to determine whether the keys to improved organizational decisions have really been rigorously studied.

More than better designs are needed however. Support for the conduct of experiments in simulators like ALCO needs to be expanded if strong induction is the goal of research. Consider a design which uses ALCO to create an organization containing a hierarchy of roles involving 12 participants. If each participant must be trained and then work in only one two-hour experimental session, and if each participant is to be a person experienced in both routine and adaptive administrative challenges, the difficulty of recruiting an adequate number (at least 720)[62] of subjects, much less giving them meaningful incentives to excel, threatens to forestall the entire effort. Only in contexts where one or more organizations sense the importance of improving organizational decision processes, and are therefor willing to encourage participation in an extensive experimental study, are meaningful experiments likely to be conducted.

Ironically, influential organizational members may not sense how pivotal decision processes are in balancing demands for routine efficiency and readiness. Thus, it seems vital to accelerate careful analyses of organizational decision making in salient situations. A good example of the kind of research which might motivate increased support for ambitious experiments is Feynman's work (1992) on the Rogers Commission. He probed relationships between individual, group and organization behaviors more aggressively than most of the other members of the Commission. Another example is Perrow's (1984) moment by moment analysis of the Three Mile Island incident.[63] A third set of examples can be found in Miller (1990). Two common themes which become apparent in these kinds of sources are: 1) the failure of those making critical decisions to think systemically rather than locally, and 2) apparent unconcern for reviewing or auditing the nature and quality of on-going decision processes in real time.[64]

Regrettably, the validity of these, and other, lessons from case studies has not been rigorously established. Not only are there no experimental data to support them, there are also no comparative case studies. While there are well known dangers to "ex-post facto" research designs (Campbell and Stanley, 1963), comparative studies would be less likely to permit common inductive errors (such as inferring the quality of a decision

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[62] This is a minimum (and rough) estimate. It assumes (only) two levels of (only) two independent variables with 12 persons per observation (each simulated organization constituting an observation). It also assumes that robust estimates of effect sizes will require approximately 15 observations in each experimental condition.

[63] Perrow's (1990) analysis (with Guillen) of decisions about how to handle the AIDS crisis may do less to increase concern with organizational decision processes. It has a much more partisan or adversarial tone than his earlier (1982) analyses.

[64] Even retrospective consideration of the nature of organizational decision processes is very unusual in these kinds of sources.

process from how good the results turned out to be - Baron and Hershey, 1988). And results of comparative studies would provide better guidance for the design of the "large" experiments which are needed for strong induction.

Given the uneveness and "thinness" of past research that was apparent in the macro analysis of Phase 1, it is difficult to make specific recommendations for "large" experiments. It does seem clear, however, that they need to incorporate at least two of the following levels of variables; individual differences (e.g., expertise, mental ability and personality), social (e.g., cohesion, extra-role behaviors like helping, and conflict management procedures), structural (e.g., distribution of decision responsibilities among members, communications centrality, and status hierarchies), and environmental (e.g, stability, and munificence).

Other factors also discourage "large" designs. Only a small minority of social scientists receive scholarly training that crosses disciplinary boundaries. Consequently they may not appreciate research outside their specialty nor know how to collaborate with scholars from other disciplines. Currently, peer-reviewed social science journals, particularly those emphasizing experimental research, fail to encourage submission of studies with more than two or three independent variables. Nor are most social science journals receptive to cross- or multi-disciplinary efforts. Coupled with the current tenure incentive system which tends to emphasize collaboration among researchers from the same discipline on projects with few independent variables, designs will tend to be rigorous but too "small" to provide insights about group or organizational decision making.[65]

If adequate experiments are mounted, their findings will need replication. While there are some programmatic efforts (e.g., Davis, Stasser) in today's "smaller" experiments, efforts which permit the same experimental contrasts to be made in more than one study, they are not common. Unfortunately, considering the resource requirements and other barriers to "large" experiments on organizational decision processes, their replication is not to be expected. This despite the fact that even relatively minor differences between apparently identical studies can produce very different results (Vidmar and Hackman, 1971). Multiple studies of the same hypothesis also need to be encouraged so that meta-analyses can be applied to establish the effect sizes of different combinations of independent variables (Hunter and Schmidt, 1990, 1994,1991).

If experimental research remains focused on "small" designs, this project documents the need to redirect those efforts to relatively neglected topics. Research on decision making has emphasized individual cognition for more than thirty years. Our project indicates that even if every individual avoided all the biases and errors documented by that research, team and organizational decisions are unlikely to provide adequate

[65] This is not to argue that all research must always involve complex judgments or decisions. It is true that sometimes "Meaningful research in [organizational] coordination and communication requires ... simple tasks." (Carley and Prietula, 1994, 82).

guidance for improving collective decision processes, particularly involving dispersed teams facing crises.

There is reason to hope that many of the obstacles encountered in this project will dissipate over the next few years. Teams of researchers from different disciplines can more readily collaborate as electronic mail and more advanced collaborative tools become endemic. If the medical model, where multidisciplinary teams are more common, is encouraged in the social sciences, projects like this will be more likely. Economic (e.g., high salary costs), demographic (e.g., a smaller student base) and technological (e.g., world-wide courses offered "by wire" over the internet or video satellite) trends paper to be encouraging change in universities. And universities are increasingly turning to corporations for support. In addition, some of the most interesting and useful social science research is increasingly conducted in corporations, think tanks, and other non-academic institutions. The combination of these events may well awaken university administrators and scholars to the need for more large scale, multidisciplinary, long term, and rigorous social science research programs. If so, the arguments and research cited in this report may be useful in redirecting some of those programs toward the study of organizational decision systems.

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Appendix 1
Vincennes' Crisis

The Navy's USS Vincennes' crisis in the Iranian Gulf is an example of the simultaneous properties of many crises. It is impossible to fully empathize with those who experienced it. However, by reading the following, intentionally unorganized, run-on, and incomplete, description the reader may be able to sense how different a real crisis can be from experimental settings.

Decisions were made by many individuals, may of whom were unable to communicate face to face. Most participants faced multiple decision tasks, each being a distraction from the others. For example, the captain needed to not only determine whether the aircraft on radar was an enemy, but also how to combat the surrounding Iranian gunboats. The situation contained unanticipated and unrecognized linkages that adversely affected the decision process. For example, sailors listening to Captain Rogers and other officers on "walk-mans" connected to the communications system drained electrical power, reducing volume so much that messages could not be heard until a circuit was "flipped." Also, guns' firing caused electrical pulses that produced light flickers which caused an officer trying to read civilian flight schedules to miss Iran Air's flight 655 listing. Mental set and mental maps contained beliefs that shaped interpretations of events. For example, as a precaution, planes were automatically designated "hostile" at takeoff from Iran's Bandar Abase airfield because both civilian and military flights originated there. In addition, everyone on board knew that Iran viewed them as serving the interests of "the great Satan." And the scenario was reminiscent of the USS Stark's when it had been seriously damaged and lives had been lost by an attack by a regional power just over a year earlier. One result of the Stark encounter was standing orders to fire first if necessary to protect crew and ship. Personal and organizational goals were incompletely aligned. Rogers' career would benefit from combat experience, but U.S. foreign policy would not be so well served. Data were ambiguous. For example, it was known that an aircraft's (civilian) identification signal could be readily faked. Radar signals were difficult to interpret. There may have been overconfidence; the Vincennes had been characterized as invincible, a "robocruiser." Communications were simultaneously excessive, noisy, and inadequate. Incoming messages from other ships and planes competed with those sent by on-board radar observers. Some personnel had separate messages coming in their left and right earphones. There was no exchange of messages with flight 655. By being restricted to electronic media many subtle messages were probably unsent or distorted. People were shouting in the command and control center. Incorrect interpretations were reinforced by their repetition, whereas an accurate dissenting view was "lost." No one could identify the person who suggested the aircraft was an (Iranian) F-14. Misinterpretations were not corrected, so the captain was told the incoming aircraft was descending. Time pressure was extreme; there was under four minutes between spotting the aircraft and the order to fire, only about 60 seconds of which were available to make the decision. Conditions were very unpleasant. Not only was it 100 degrees and very noisy, but the ship was exposed to possible mortal threat. Despite the Navy's emphasis on keeping cool under fire, emotions were elevated, enhancing reliance on dominant behaviors and beliefs.

Appendix 2

Examples of Simulation Research at Different Levels of Behavior

Individual Behavior:

EPAM: Serial processing recognition-based expertise including learning mechanism for acquiring chunks stored in memory. Predicts behavior reported in the verbal learning literature. Feigenbaum, E., and Simon, H. (1984) DPAM-like models of recognition and learning. *Cognitive Science*, 8, 305-336.

ISACC: Encodes natural language statements of physics problems into internal images, using the images to produce equations which it solves. Novak, G. (1976) Computer understanding of physics problems stated in natural language. Technical Report Number NL-30. Austin, TX: Department of Computer Science, University of Texas.

UNDERSTAND: Encodes natural language descriptions of puzzles into internal representations that are suitable problem spaces for GPS. See Hayes, J., and Simon, H. (1974) Understanding written problem instructions. In Gregg, L. (Ed.) *Knowledge and Cognition*. Hillsdale, NJ: Erlbaum, 167-200.

Group Behavior:

DISCUSS: Models effects of various distributions of private knowledge in decision making groups. Stasser, G. (1988) Computer simulation as a research tool: The DISCUSS model of group decision making. *Journal of Experimental Social Psychology*, 24, 393-422.

SIS: Explores relationships between decision schemes and distributions of opinion in decision making groups. Stasser, G, Kerr, N., and Davis, J. (1989) Influence processes and consensus models in decision-making groups. In Paulus, P. (1989) *Psychology of Group Influence* (2nd edition). Hillsdale, NJ: Erlbaum, 279-326.

Organizational Behavior:

CONSTRUCT: Investigates changes in social/organizational structure which arise as members gather, interpret and communicate data. Individual component is capable of learning. Carley, K. (1988) Social stability and constructionism. Pittsburgh: Social and Decision Sciences Working Paper Series, Carnegie Mellon University.

CORBIN: Battlefield simulator in which individual behavior is often in the form of small expert systems C3MUG, Communications, Command and Control Military Users Group.

GARCORG: Interactive model explores relationship between structure, "event theater" and decision making capability of the organization. Carley, K. (1986) Measuring efficiency in a garbage can hierarchy. Chapter 8 in March, J., and Weissinger-Baylon, R. (Eds.), *Ambiguity and Command*. Boston: Pitman, 165-194.

X-NET: Reveals which organization links strengthen and which links atrophy as a result of resource exchange decisions in whatever network a researcher specifies. Markovsky, B. (1987) Toward multilevel sociological theories: simulations of actor and network effects. *Sociological Theory*, 5, 101-117.

Appendix 3
Key Words or Phrases Used in Macro-Analysis

ambiguity
architecture, organizational
architecture, cognitive
assessment
chance
chaos
choice
cognitive map
cognitive complexity
cognitive style
cohesiveness
confidence
conflict, cognitive
conflict, goals
control
coordination
crisis
decision
diffuse decision or problem
dilemma
distraction
distributed problem
distributed knowledge
distributed intelligence
distributed decision
dynamic
environmental predictability
error
experience
estimate / estimation
experiment
expert system
expertise
feedback
forecasting
group decision rule - social decision scheme
group performance
groupthink
hostility
hypothesis generation
image theory
information, location
information, reliability
information, validity
information, quantity/load
information, completeness
information, timeliness
interpersonal conflict
judgment
linking-pin
learning
load, work
mental model
minority influence
network
overconfidence
overload
probability
redundancy in goals (over people or units)
redundancy in mental models (over people)
redundancy in cues (within an individual)
redundancy in organizational structures (e.g., status congruency)
redundancy in access to information (over people)
redundancy in communications links (between people or units)
risk
schema
script
search
simulation
social decision scheme
stress / tension
structure(s) (of organization)
structure(s) (of access to information)
surprise
system
thought experiment
threat
time pressure / deadlines
turbulence
turnover (in people, units, hardware)
uncertainty

Appendix 4
Criteria for Deletion of Studies in Macro-Analysis

If any of the following characterized a study it was eliminated from consideration.

abnormal psychology studies,
developmental or age studies,
studies not reported in English,
studies involving lexical tasks,
research on trivial signal detection, visual or auditory reaction time tasks,
gender studies,
investigations of the effectiveness of college career choice aids,
experiments using simple recall tasks,
research reporting the development of measures, assessments of measures' reliability or validity, or other investigations of a measure's psychometric properties,
investigations using trivial ergonomics (e.g., 1 button vs. multi-button vending machines) or motor skills,
clinical, clinical technique development studies,
strictly physiological studies,
experiments with simple recognition tasks,
sexual function or dysfunction research,
studies of highly specific tasks (e.g., highway curve driving),
studies previously considered in editing other searches,
alcohol/drug abuse studies,
quality of instruction studies,
studies not published in top tier, peer-review journals,
nonexperimental studies, and non-empirical articles, such as literature reviews and essays.

Appendix 5
Journals Sampled to Verify PsycLIT Search Results

Management:
- Industrial Crisis Quarterly
- Organizational Behavior and Human Decision Processes
- Academy of Management Journal
- Administrative Science Quarterly
- Journal of Consumer Research
- Organization Science

Psychology:
- Journal of Applied Psychology
- Acta Psychologica
- Journal of Personality and Social Psychology
- Journal of Experimental Psychology
- Journal of Experimental Social Psychology
- Cognition
- Psychological Review
- Psychological Bulletin
- Annual Review of Psychology
- Advances in Experimental Social Psychology

Engineering:
- IEEE Transactions on Systems, Man and Cybernetics
- International Journal of Man-Machine Studies

Sociology:
- Annual Review of Sociology
- Social Psychology Quarterly (Sociometry)
- Social Networks
- Journal of Mathematical Sociology

Communications:
- Human Communication Research
- Small Group Research (Small Group Behavior)
- Communication Monographs
- Communication Studies

Other:
- Journal of Conflict Resolution
- Behavioral Science
- Journal of Economic Behavior & Organization
- Human Computer Interaction

Appendix 6
Consolidated Key Word Sets - Second Matrix

Set 1: Process Factors

- assessment / evaluation
- choice / decision
- communicate / coordinat(e) / control
- estimate / estimation
- forecast(ing) / predict(ing)
- judgment
- knowledge / information
- search / problem finding / hypothesis generation
- memory / learning

Set 2: Context or Outcome Factors

- achievement / accuracy
- error
- calibration / resolution
- ambiguity
- risk / uncertainty
- chance
- channel
- chaos / dynamic / turbulence
- cognitive complexity / cognitive style
- cognitive map / mental model / policy
- confidence / overconfidence / underconfidence
- conflict / dissent
- crisis / emergency
- deadline / pressure / load
- diffuse / distributed / decentralized
- dilemma / public good / free rider
- minority influence
- distraction
- experience / expertise
- cohes(ion) / morale / satisfaction
- expert system
- feedback
- groupthink / conformity
- heuristic / decision rule
- hostility / environmental predictability
- image theory
- influence / persuasion
- linking pin
- locus
- location
- network
- structure
- architecture
- organization
- system
- overload
- performance / efficiency
- quality / speed / cost
- power / status
- probability / frequency
- schema / script
- shared / redundancy / duplic(ation) / overlap
- simulation / experiment
- social / interpersonal
- social decision scheme / group decision rule
- stress
- tension
- surprise / shock / threat
- turnover

* * * * * * * * * * * *

Groupings of Set 2 Variables (Rows of third matrix):

"Accuracy" - achievement or accuracy, error, and calibration or resolution.
"Risk" - ambiguity, risk or uncertainty, chance, and probability or frequency.
"Environment" - chaos or dynamic or turbulence, and hostility or environmental predictability.
"Mental Model" - cognitive complexity or cognitive style, cognitive map or mental model or policy, experience or expertise, image theory, and schema or script.
"Crisis" - crisis or emergency, stress, and surprise or shock or threat.
"Outcomes" (other than "accuracy") - cohesion or morale or satisfaction and quality or speed or cost.
"Collective" - Conflict or dissent, diffuse or distributed or decentralized, minority influence, groupthink or conformity, influence or persuasion, network, structure, architecture, organization, system, power or status, shared or redundancy or duplicate, or overlap, and SDS (social decision scheme) or group decision rule.
"Miscellaneous" - The remaining 17 items.

Appendix 7
Key Components of ICARUS:

The generic event handler. This component controls the order in which the simulator processes events as the scenario unfolds. This is based on a translation of a well tested package originally written in Pascal. The Ada version has been thoroughly tested.

The random number generator. This is used to introduce elements of chance into the simulation, for example, in the modeling of the probability that when a person reads a meter, they will misread it, or the probability that when a person tells something to another, they will be misunderstood. This is based on a well understood standard package, and the Ada version has been tested to conform to the standard.

The generic list manager. This component is used to manage groupings such as the lists indicating who is where, or the lists of rules maintained for each person. This has been thoroughly tested.

The name manager. This component is used to handle the printable names of model components so that the output from the simulation is in terms readily understood by humans. This has been thoroughly tested.

The lexical analysis package. This is used to aid in processing textual material describing the model. This is based on well tested Pascal code and has been thoroughly tested.

The common types package. This contains definitions of quantities needed throughout the simulator.

The population manager. This contains the action routines and data structures used to model each participant in the simulation.

The geography manager. This package contains information about places in the model.The value manager. This package supports the set of values that may be taken on by the variables in the model. Currently, only numeric and discrete symbolic values are supported.

The variable manager. This package stores the variables and manages their interpretation.

The expert system package. This package encapsulates the rule base used by each simulated participant. It is only partially written and incompletely specified.[66]

The knowledge manager. This package manages the system of beliefs held by each participant. Participants may hold beliefs about any variable in the model

The expression manager. Each rule in the expert system involves expressions that combine beliefs about certain values to determine what actions to take. This package handles the storage and evaluation of such expressions.

The action manager. Each rule in the expert system may specify the actions a participant will take when some condition is met. This package is used to manage such actions, but it has not yet been possible to fully specify all the possible reactions.

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[66] We wished that standard expert systems could be used, but our model requireed that each participant be able to have different beliefs about the values of the variables in the model, and current expert systems are ill-suited to this context and difficult to use as components of larger software systems.

Appendix 8
ALCO Variables

ALCO INDEPENDENT VARIABLES:[67]

1. Basic Independent Variables:
   a. Instructional manipulations - In addition to all the independent variables which follow, an experimenter may use custom "help screens" to manipulate experimental instructions of any kind that are to differ between sessions. For example, if running three teams of subjects in a session, the teams may be told they are competing, cooperating, or instructed to do their best.
   b. Number of trials
   c. Number of team members (12 maximum)
   d. Quality of information per amount spent - "Variance Factors" or VFACTOR - (manipulated using a formula); may be the same or differ by member. Once set it remains fixed throughout the session.
   e. Average size of variance factors - "High vs. low" linkage of amount spent on "search" and quality of information obtained from it
   f. Average size of correct value for each variable in organizing principle - normally will be different for each member
   g. Organizing principle - Nature of the mathematical operators and member weights relating each member's estimates to the most accurate team estimate - Can be used to manipulate relative importance of each member's accuracy to team accuracy
2. Budget Independent Variables:
   a. Pooled versus individual budget(s)
   b. Initial budget amount for each member
   c. Initial budget level (average if each member has a budget) - Can be thought of as initial wealth of team
   d. Ability to transfer funds between members - (same for all members; 0 cost for each transfer)
   e. Minimum cost/charge required to acquire information
   f. Amount of additional funds to be injected to budgets during session
   g. Trial(s) in which injections of funds (if any) are to take place (same for all members)
3. Payoff Independent Variables:
   a. Maximum possible payoff to team for perfect accuracy - Can be thought of as degree of monopoly power, environmental "support"
   b. Reward/Payoff factors - Amount of payoff to ALCO as a function of team's accuracy of estimation (manipulated using a formula involving both a linear and a quadratic penalty for inaccuracy) - To what extent does the team's payoff vary with team accuracy?
   c. Payoffs may be added either to the team's pool, or distributed to individual budgets (if the latter are part of the design) (P/I)
   d. Proportion of the total team payoff received by each player (if payoffs are distributed to individual budgets)
   e. Distribution dynamics - If payoffs are distributed to members, proportion distributed to each member can change over trials as a function of each member's past accuracy (relative to other members' accuracies) - By setting "alpha value" to 0 there are no dynamics; setting it to 1 permits payoff distributions to depend solely on the players' accuracies in the last trial; values between 0 and 1 use an exponential smoothing of accuracies for several trials with differing emphasis on the last distribution and accuracies.
4. Communications Independent Variables:
   a. Possibility of communication between members - Can any one way channel ever exist between any pair of members?

[67] Notes on independent variables:
In this appendix funds and budgets refer to resources available to members.
Some independent variables can also be manipulated between trials.
Certain independent variables can only be used when the individual budget manipulation is used. Some manipulations can only be used if communications between members are permitted.

b. Initial communications network (if communication is possible) - specified using a "from - to" matrix to create (e.g.) "wheel," "chain," "circle," etc.
c. Modifiability (by members) of initial communications network (if any)
d. Blocked channels - Are there some channels that can never be opened?
e. Cost per "one-way" channel opening (if network can be modified) - (paid from opener's budget if there are individual budgets, otherwise paid by pool budget) - Can be defined separately for each opener-openee pair
f. Cost per communication sent - "rent" (paid from sender's budget if there are individual budgets, otherwise paid by pool budget) - Can be defined separately for each sender-receiver pair

5. Feedback Independent Variables - Select which items are to be used for each trial (same items for every member):
    a. Member's estimate
    b. Correct estimate for member's parameter.
    c. Absolute error of member's estimate
    d. Relative error of member's estimate
    e. Estimate of team
    f. Correct team estimate
    g. Absolute error of team
    h. Relative error of team
    i. Payoff of team
    j. Proportion of team's payoff received by member
    k. New (current) budget
6. Auditing Independent Variables:
    a. Possibility of auditing others' behaviors (ability can be defined separately for each pair of members) - Only information about the most recent trial can be obtained from an audit
    b. If auditing is possible, what information about auditee can be audited? Any combination of the following is possible:
        i. Amount spent for information by auditee
        ii. Correct answer for auditee's parameter
        iii. Estimate of auditee's parameter by auditee
        iv. Absolute Error in auditee's estimate
        v. Budget of auditee.
    c. Cost per audit (paid by auditor's budget if there are individual budgets, otherwise paid by pool budget) - Can be defined separately for each auditor-auditee pair

ALCO DEPENDENT VARIABLES - The following data are automatically collected. Additional dependent measures are often obtained by using paper and pencil questionnaires.

1. Financial Dependent Variables:
    a. Amount spent for information - by member and trial
    b. Amount spent on channel creation by opener-openee pair
    c. Amount spent on messages by sender-sendee pair
    d. Amount spent on audits by auditor-auditee pair
    e. Amount of funds transferred by pair of members and trial
    f. Payoff received by team on each trial
    g. Payoff received by each member on each trial
    h. Budget level (individual or pooled) at all times
2. Communications Dependent Variables:
    a. Number of one way channels opened by openee-opener pair
    b. Number of messages sent by sender-receiver pair
    c. Number of audits by auditor-auditee pair
    d. Contents of messages - Text file saves all transcripts
3. Performance Dependent Variables:
    a. Estimate of own parameter value for each member
    b. Correct parameter value for each member

c. Absolute error of member's estimate on each trial
d. Relative error of member's estimate on each trial
e. Absolute error of team's estimate on each trial
f. Relative error of team's estimate on each trial
g. Time duration and latency measures - All activities are time stamped
h. Number of trials (if session ends due to depletion of budget)

Addendum 1
Project Products

Published Reports:

Jones, D. Simulation of information flow in organizations. *Proceedings of the IEEE Winter Simulation Conference*, Los Angeles, December 1992.

Invited Presentations:

Rose, G., and Conlon, E. ALCO - An Organizational "Flight Simulator." Presented to the TIMS/ORSA Mathematical Organization Theory Workshop, Chicago, IL, May 15-16, 1993.

Rose, G. Learning from Experiments on Organizations: Lessons from ALCO. Presented at the national meeting of INFORMS (TIMS/ORSA), April 23, 1995.
Learning from Experiments on Organizations: Lessons from ALCO. Presented at the national meeting of INFORMS (TIMS/ORSA), April 23, 1995.

In response to an inquiry by Howard Berg, deputy director of ASSET,[68] two Ada packages developed for this project were contributed to ASSET. One is a pseudo-random number generator package; the other a generic pending-event-set management package. These are core components of ICARUS and are applicable to many other simulation

[68] ASSET - Asset Source for Software Engineering Technology was organized by the Defense Advanced Research Projects Agency (DARPA) under its Software Technology for Adaptable, Reliable Systems (STARS) program. DARPA tasked IBM and its principal subcontractor, SAIC, (Science Applications International Corporation) to establish the ASSET reuse library to serve as a national resource for the advancement of software reuse across the DoD. ASSET's mission is to provide a distributed support system as a focus for software reuse within the DoD and to help foster a software reuse industry within the United States.